SABINE LAKE CONFERENCE

Where Texas and Louisiana Come Together

Art by Isabelle Chapman

ECOLOGY • HABITAT • STEWARDSHIP

September 13-14, 1996
Beaumont, Texas

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rted in part by Institutional Grant NA56RG0388 to Texas A&M University from the National Sea
ınal Oceanic and Atmospheric Administration, U.S. Department of Commerce. TAMU-SG-97-101.

Contents

FOREWORD

The Sabine Lake Conference is an attempt to establish an environmental baseline for Sabine Lake and surrounding uplands and wetlands in Texas and Louisiana. The presentations included in this publication were selected to provide an overview of the climatologic, geologic, hydrologic, ecologic and economic conditions associated with the lake as well as stewardship issues in both states.

The Sabine Lake Conference is funded in large part by the Trans-Texas Water Program, Southeast Study Area, through a contract with Brown & Root, Inc. of Houston. Special thanks go to Amy Schumacher, Mary Carter and Paulette Woods of Blackburn & Carter in Houston and Glenda Callaway of Ekistics Corporation in Houston for their work in organizing the conference and working to put this publication together. Special thanks also go to Texas A&M Sea Grant for publishing these proceedings.

This conference and these proceedings were organized because most people within the Sabine Lake basin felt there was little published information about the lake that was usable and easily available. The intent of this publication is to begin the task of developing documentation of the baseline conditions in this vibrant region and to provide a basis for better understanding the structure and function of the natural and social resource base. Because many of these subjects had not been documented previously, a note of special appreciation is extended to the authors that have worked so hard to compile these written materials.

James B. Blackburn, Jr.
Conference Coordinator

SABINE LAKE CONFERENCE AGENDA

Friday, September 13, 1996

8:00 - 8:45 a.m. **Registration**

8:45 - 9:20 a.m. **Welcome and Introductory Remarks**

9:20 - 10:00 a.m. **Geology and Sediments**

Historical development of the Sabine Lake and Calcasieu Lake systems, including the role of sediment inflow in marsh formation.

Robert Morton, Ph.D., Bureau of Economic Geology, University of Texas - Overview of historical development of Sabine Lake.

Woody Gagliano, Ph.D., Coastal Environments Inc. - Overview of historical development of Calcasieu Lake system

10:15 - 11:45 a.m. **Climate and Hydrology**

Climate, rainfall, inflows and circulation within the Sabine Lake system.

George Bomar, Texas Natural Resource Conservation Commission - Climate and its influence on the Sabine Lake area.

Tom Gooch, Freese and Nichols, Inc. - Rainfall patterns and historical inflow from the Sabine and Neches Rivers into Sabine Lake.

Ronnie Paille, U.S. Fish and Wildlife Service - Water exchange patterns and salinity of marshes between Calcasieu and Sabine Lakes.

Joseph Subayda, Ph.D., Louisiana State University - Influence of the Gulf Intracoastal Waterway on circulation in the Sabine Lake and Calcasieu systems.

Peter Mantz, Ph.D., Lamar University - Tidal circulation in Sabine Lake.

Gary Powell, Texas Water Development Board and Al Green, Texas Parks and Wildlife Department - Freshwater inflow modeling for Texas bays and estuaries.

12:00 - 1:15 p.m. **Lunch**

Don Davis, Louisiana State University - History of the Sabine Lake Area.

1:30 - 2:30 p.m. **Water Quality**

Baseline water quality description of the Sabine Lake system.

Jack Tatum, Sabine River Authority of Texas - Water quality in the Sabine River.

Dennis Becker, Lower Neches Valley Authority - Water quality in the lower Neches River.

Alan Plummer, Jr., P.E., Alan Plummer and Assoc., Inc. - Water quality in Sabine Lake.

Mike Waldon, Ph.D., University of Southwestern Louisiana - Water quality in Calcasieu Lake.

2:30 - 3:30 p.m. **Habitat/Coastal Marshes**

Habitat in Sabine Lake area and changes over time in the marsh system.

Jim Sutherlin, Texas Parks and Wildlife Dept. - Historical development of the marsh system on the west side of Sabine Lake.

Will Nidecker, U.S. Fish and Wildlife Service - Historical development of the marsh system on the east side of Sabine Lake.

Andy Sipocz, Texas Parks and Wildlife Department - Vegetation succession in the Sabine Lake marshes.

Bill White, Ph.D., Bureau of Economic Geology, University of Texas - Wetlands changes associated with faulting and subsidence.

3:45 - 5:00 p.m. **Biological Components**

Baseline characterization of the Sabine Lake ecosystem and its biological components.

Bob McFarlane, Ph.D.; McFarlane and Associates - Conceptual ecosystem model for Sabine Lake.

Phil Bowman, Louisiana Department of Wildlife and Fisheries - Characterization of fishery and fishing in Louisiana waters of Sabine Lake.

Jerry Mambretti, Texas Parks and Wildlife Department - Characterization of fishery and fishing in Texas waters of Sabine Lake.

Diane Borden-Billot, U.S. Fish and Wildlife Service - Waterfowl in the Sabine Lake ecosystem.

5:00 - 8:00 p.m. **Reception and Poster Session**

Saturday, September 14, 1996

8:00 - 8:45 a.m. **Registration**

8:45 - 9:00 a.m. **Welcome and Introductory Remarks**

9:00 - 10:00 a.m. **Human Uses**

Trends and projections of human uses of the Sabine Lake system, area growth and economy.

Paul Coreil, Louisiana Sea Grant, Louisiana State University - Overview characterization of human uses of Sabine Lake area.

Dewayne Hollin, Texas Sea Grant, Texas A&M University - Overview of industrial uses of the Sabine Lake system.

Don Hoyte, Texas Comptroller's Office - Future growth in the Sabine Lake area.

10:15 - 11:15 **Institutional Management Issues**

Governmental agencies and policy making for the Sabine Lake area.

Bruce Moulton, Texas Natural Resource Conservation Commission - General description of Texas agencies with responsibility for Sabine Lake.

Mike Wascom, Louisiana Sea Grant, Louisiana State University - General description of Louisiana agencies with responsibility for Sabine Lake.

George Ward, Ph.D., Center for Research in Water Resources, University of Texas - Models and decision making for the lay person.

11:15 - 12:00 **Physical Management Issues**

Current water management practices in the Sabine Lake area.

Ron Marcantel, U.S. Natural Resources Conservation Service - Existing management practices around Sabine Lake.

Rey Sorgee, U.S. Corps of Engineers Fort Worth District - Water management in the Sam Rayburn and B.A. Steinhagen Reservoirs.

Barton Rumsey, Sabine River Authority of La.- Water management in Toledo Bend Reservoir.

12:00 - 1:15 p.m. **Lunch**

Tina Horn, Cameron Parish, representing the Governor's Office, State of Louisiana - Louisiana outlook for Sabine Lake area.

John Howard, Governor's Office, State of Texas - Texas outlook for Sabine Lake area.

1:30 - 2:15 p.m. **Summary**

James B. Blackburn, Jr., Blackburn and Carter - Summary of conference presentations and introduction to afternoon discussion panel.

2:15 - 4:00 p.m. **Summary Panel**

Panel will discuss material presented at the conference and the question of goals for management of the Sabine Lake system.

Panel Members:

Randy Roach (Moderator)

Terry Howey, Louisiana Coastal Zone Management.
Peter Ravella, Texas Coastal Management Program.
Mike Foster, Sabine Lake Foundation.
Ann Burruss, Coalition to Restore Coastal Louisiana.
David Richard, Louisiana local citizen.
Ron Sigler, Texas local citizen.
Danny Choate, Sabine River Compact Commission.

Presentors and representatives of state and local natural resource agencies will be available to respond to questions and provide information.

4:00 p.m. **Conference Close**

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Base funding for the Sabine Lake Conference was provided by the sponsors of the Southeast Study Area of the Trans-Texas Water Program.

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Jerry Mambretti
Texas Parks & Wildlife Department

Peter Mantz
Civil Engineering Department, Lamar University

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U.S. Natural Resource Conservation Service

Robert McFarlane
McFarlane & Associates

Rick Medina
U.S. Corps of Engineers, Galveston

Earl Melancon
Nichols State University

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San Jacinto River Authority

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Texas Natural Resource Conservation Commission

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Mike Waldon
Civil Engineering Department, University of Southwestern Louisiana

George Ward
Center for Research in Water Resources, University of Texas

Gerry Wermund
Bureau of Economic Geology, The University of Texas

Terry Whitledge
Marine Science Institute, The University of Texas

BIOGRAPHIES OF SPEAKERS

Diane L. Borden-Billiot has been employed by the U.S. Forest Service as a Wildlife Biologist at the Sabine NWR for the past five years. Prior to that she worked for the U.S. Forest Service as a Wildlife Biologist at the Southeast Forest Experiment Station in Clemson, SC. She received a BS in Environmental Science with emphasis in Wildlife Management from Unity College, and a MS fin Biology with emphasis in Wildlife Management from Tennessee Tech University.

Dennis Becker is the Water Supply and Quality Manager for the Lower Neches Valley Authority in Beaumont. He was employed by LNVA in 1981 as Projects Coordinator, attained his present position in 1995, and has been involved with environmental planning and permitting, water quality monitoring, pumping plant operations and oversight of special projects. LNVA is the principal distributor of fresh water for use by cities, industries and farmers in Southeast Texas.

James B. Blackburn, Jr. is an environmental lawyer and planner. He teaches Environmental Law and Global Environmental Law at Rice University, where he is also a research associate at the Energy & Environmental Systems Institute, studying sustainable development concepts, and is helping to organize the 1997 DeLange/ Woodlands Conference on Sustainable Development. He received a B.A. in History from U.T., Austin (1969), a J.D. in Law from U.T., Austin (1972), and an M.S. in Environmental Science from Rice (1974). His law practice involves litigation and consultation on air quality, land contamination, risk assessment, environmental auditing and zero discharge planning, as well as natural resource issues such as wetlands, flooding and endangered species.

Ann Burruss has been the Science & Technology Director for the non-profit group the Coalition to Restore Coastal Louisiana since October, 1994, whose mission is to advance the overall progress of coastal restoration in Louisiana. She is responsible for integrating science and technology issues in support of the Coalition's mission, and provides scientific review and guidance on various coastal restoration plans, projects, legislation and other actions. She received her BS in Biology from Longwood College in VA, and her Master of Science in Environmental Science from the University of North Carolina-Chapel Hill.

David V. Cardner was appointed Sabine River Compact Commissioner by Governor Clements from 1982-1986, was reappointed in 1989, and continues serving in that capacity today. As Compact Commissioner for Texas, he works to maintain a cordial relationship with Louisiana members of the Administraiton and to develop tools and procedures for measuring and controlling water-related activities. Upon receiving his doctorate from Rice University in 1963, he joined E. I. DuPont de Nemours, where he served in management and technical positions in research and plant technical. In 1993 he retired from DuPont and started with Lamar University, where he serves as Deputy Director of the Electronic Commerce Resource Center.

Paul D. Coreil is an Area Agent for the Wetland and Coastal Resources. He has a BS in Zoology, an MS in Wildlife Management, and he received his Ph.D in Extension Education, with a minor in Agricultural Economics from Louisiana State University in 1995. He has many organization/task force affiliations, a few of which are: Louisiana Wildlife Biologists Association, Louisiana Land and Water Conservation Plan Development Committee, and DCRT's Recreation, Tourism, and Wildlife Committee. Special interest areas include wildlife ecology, natural resource management in wetlands, natural resource economics and Extension Education.

Donald Davis is the Administrator of the Louisiana Applied and Educational Oil Spill Research and Development Program. Since completing his Ph.D. at LSU, he has investigated various human/land issues in Louisiana's wetlands and written or co-authored more than 90 articles related to various coastal-related issues. He is currently working on a number of problems related to the oil and gas industry in South Louisiana, along with projects that will help restore Louisiana's wetlands.

C. Michael Foster joined the South East Texas Regional Planning Commission in October, 1988. He attended Lamar University, where he received a BS in Ocean

Technology, and then attended Texas A&M University in College Station and also Moody College of Marine Technology in Galveston, where he took courses in marine biology and post-graduate courses in oceanography.

Sherwood Gagliano is the President of Coastal Environments, Inc. in Baton Rouge, LA. He obtained his Ph.D. from LSU in 1967, and his specialties include coastal zone management, , natural systems management, environmental processes, coastal and alluvial geology, mariculture, archaeology, physical and cultural geography, and forensic geology and geography. He obtained his current position as President of Coastal Environments in 1975, and his most recent experience includes Co-Principal Investigator for the master plan for conservation and restoration of Louisiana's coastal wetlands.

Albert W. Green is the Aquatic Studies Branch Chief for the Texas Parks and Wildlife Department's Resource Protection Division, which has the responsibility to determine instream flow and freshwater inflow needs to maintain healthy streams, rivers and estuaries in Texas. The Aquatic Studies Branch has the responsibility to review all water right applications and make recommendations for flows that will protect these systems from degradation that could be caused by water storage or diversions. He has a Bachelor of Arts in Zoology from the University of Texas in Austin, and a Masters of Science with emphasis in Community Ecology and Statistics from the University of Houston.

Dewayne Hollin has been Marine Business Management Specialist for the Sea Grant College Program at Texas A&M University since 1972. He received both his BBA and MBA from the University of Houston. He currently provides advisory services for marine-related business operating along the Texas Gulf Coast, plans and coordinates training programs and seminars in the areas of safety, business management and economics, marketing, environmental issues, recreational boating and commercial fishing, and conducts basic research on environmental issues, recreational boating, marine industrial development and commercial fishing industry safety.

Robert McFarlane is the Principal Ecologist and owner of McFarlane & Associates in Houston, Texas, which specializes in the design, implementation, analysis and management of environmental impact assessments, site evaluations and feasibility studies, and the development of mitigation strategies to reduce or eliminate the adverse environmental consequences of development projects. He obtained his Master of Science and Doctor of Philosophy degrees in Zoology from the University of Florida, and has certifications as Senior Ecologist, Wildlife Biologist and Fisheries Scientist.

Jerry M. Mambretti is the Sabine Lake Ecosystem Leader for the Texas Parks & Wildlife Department, Coastal Fisheries Branch in Port Author. He obtained this position in December, 1992, and is responsible for orchestrating all programs, activities and personnel, supervising members of the Resource Monitoring Project, and coordinating all fiscal and physical needs of Coastal Fisheries at the Port Arthur field Station, as well as serves as Texas' representative on Gulf States Fishery Management Commission's Menhaden Advisory Committee. He received a Bachelor of Science in 1978, and a Masters of Science in 1983 from Midwestern State University, Wichita Falls, Texas.

Peter A. Mantz has been a professor at Lamar University, Dept. of Civil Engineering since 1991, and was an Associate Professor, 1982-1991. He earned his Msc in Oceanography at Southampton University, UK, 1970, his Ph.D. in Civil Engineering at London University, UK, 1975, and became a Master Mariner in 1980, Foreign Going, UK. He has authored 10 Consulting Engineering Reports, published 10 papers on Engineering Education, and published 25 papers on sediment research, among which are: "Hydrodyamic modeling of the Sabine-Neches Estuary", Proc. 1995 Annual Meeting of the Gulf-Southwest ASEE, Beaumont, TX (jointly written with Dong, A.), and "Hydrodynamic model of the Beaumont Flood of October, 1994", Texas Section Assoc. (jointly written with Dong, A.).

Ron Marcantel is with the Natural Resources Conservation Service in Lake Charles, LA. He obtained his BS in Horticulture from McNeese State University, Lake Charles, LA. He has worked for NRCS (formerly called the Soil Conservation Service) for 21 years. He has been working in Louisiana Coastal marshes since 1990, primarily assisting landowners/managers on erosion control methods that are compatible with biological resources.

Robert A. Morton is a Senior Research Scientist with the Bureau of Economic Geology at the University of Texas in Austin. He received his bachelors degree from the University of Chattanooga and his masters and doctoral degrees from West Virginia University. Since joining the Bureau in 1972, he has conducted research in coastal and marine geology with an emphasis on modern coastal environments and coastal processes. For the past 20 years he has supervised or co-supervised the Bureau's coastal program. He is currently an Associate Editor of the Journal of Sedimentary Research and is on the editorial board of the Journal of Coastal Research.

Bruce A. Moulton is a Technical Specialist in the Water Policy and Regulations Division, Office of Policy and Regulatory Development at the Texas Natural Resource Conservation Commission. Prior to his current position, he worked with the State water agencies from 1976 to 1993. Present responsibilities include Gulf of Mexico Program - Freshwater Inflow Committee, Nueces Estuary Advisory Council, Corpus Christi Bay National Estuary Program - Scientific and Technical Advisory Committee, TransTexas Water Program, Consensus-based State Water Planning, Texas Coastal Management Program, Water policy and rules development, and special projects involving environmental analysis for surface water resource development.

A. W. "Will" Nidecker, III, is the Refuge Manager for the Sabine National Wildlife Refuge in Hackberry, Louisiana. Prior to this, he has positions as Refuge Manager and Assistant Refuge Manager at the Imperial NWR in Arizona, Sherburne NWR, Minnesota, the Montezuma NWR, New York and the Great Swamp NWR in New Jersey. He received his BS in Wildlife Management from the College of Emporia,Kanasas and University of Maine.

Ronny Paille currently works for the

US Fish & Wildlife Service in the Ecological Services Division at Lafayette, LA on marsh management and coastal wetland restoration activities. He obtained a BS in Zoology from LSU in 1977, and MS degree from LSU Marine Sciences Dept., 1980. His experience includes fisheries research at Sabine NWR and on the Cameron-Creole Watershed at LSU Cooperative Fisheries Unit, a biologist for the Little Pecan Hunting Club, and a biologist for the USFWS, Sabine NWR.

Gary Lee Powell is the Texas Water Development Board's Environmental Section Chief and Director of the Bays and Estuaries Program. He obtained his BS degree in Zoology (Chemistry minor) from Indiana University, 1969, and performed his post-graduate and doctoral studies at the University of Texas in Austin, 1969-75, where he graduated in Vertebrate Zoology (Ichthyology). Gary has also served as an expert member of federal research and risk advisory panels for the US Departments of Interior, Commerce and Energy, as well as the US Environmental Protection Agency.

Alan H. Plummer, Jr. is the President of Alan Plummer Associates, Inc., and a professional environmental engineer with more than 30 years of experience with water quality and storm water management and planning, as well as wastewater and water treatment and system projects for municipal, regional and industrial clients. He received his Master of Science degree in Environmental Health Engineering from the University of Texas, Austin, 1968, his BS in Civil Engineering from Lamar University, 1964, and is a registered professional engineer in Texas, Arkansas, Louisiana and Oklahoma. In 1994 he served as President of the Texas Water Conservation Association, and is a Diplomat in the American Academy of Environmental Engineering,.

David Richard has been the Executive Vice President for Stream Property Management, Inc. since 1991. He is responsible for the management of 250,000 acres of diverse types and locations, and represents clients on managed lands issues affecting owners rights on a local, state and national level. He has a BS in Biology from Lamar University. He is a member of several professional organizations, among which are Louisiana Wildlife Biologists Association, Louisiana Alligator Farmers and Ranchers Assoc. (Board of Directors, and is a member of the Monitoring, Evaluation and Research Team for the Gulf Coast Joint Venture, North American Waterfowl Management Plan.

Barton Rumsey is the Engineer Manager for the Sabine River Authority in Louisiana and Project Supervisor for Engineering for the Toledo Bend Project Joint Operation. He graduated from Louisiana Tech in Ruston, LA with a BS in Civil Engineering, and is licensed in LA as a Professional Engineer in Civil Engineering and as a Professional Land Surveyor. He has been an engineer with the Louisiana Department of Transportation and Development for eight years, and has twenty-six years experience as an engineer with the State of LA Toledo Bend Reservoir.

Andrew Vincent Sipocz received his BS in Forestry from Purdue University, and while there, worked for the Indiana Dept. of Natural Resources Fish & Wildlife Division. He obtained his Masters of Science from Texas A&M's Wildlife and Fisheries Department in 1993. He began work for the Texas Parks & Wildlife Department's Resource Protection Division in 1990, which entails working with development interests, private landowners, and public conservation groups to conserve wetland habitats as well as assist research and management of wetland habitats.

James A. Sutherlin has worked for the Texas Parks and Wildlife Department as Area Manager of the J.D. Murphree Wildlife Management Area, and as Project Leader of the TPWD Wildlife Division's Upper Coast Wetland Ecosystem Project in the upper coastal counties of Texas since 1990. He has a BS from the Department of Wildlife and Fisheries Sciences from Texas A&M University, College Station. His professional positions include Chair, The Texas Chenier Plain Initiative, Gulf Coast Joint Venture, NAWMP, President, 1996-97, Texas Wildlife Management Council.

Jack W. Tatum has been with the Sabine River Authority of Texas since 1971, and currently is their Development Coordinator. He received his BS in Biology, with a minor in Chemistry, 1968, then obtained a MA in Aquatic Biology with a minor in Chemistry, in 1970, all from the Southwest Texas State University, San Marcos, Texas. Professional organizations to which he belongs include the National Water Resources Association, Texas Rivers and Resources Management Society, the Texas Water Conservation Association, and the Water Environment Association.

Michael Gene Waldon is an Associate Professor-Research for the Department of Engineering, Center for Louisiana Inland Water Studies at the University of Southwestern Louisiana. His education includes a BS in Biomedical Engineering, an MS in Bioengineering. He obtained a Ph.D. in Systems Engineering from Case Western Reserve in 1979, and is a Louisiana Professional Engineer (Environmental). His current research involves dissolved oxygen budget and sedimentation patterns in the Atchafalaya Basin, LA, tracking model for river oil spills, and water quality monitoring and modeling in estuaries and inland streams.

George H. Ward, Jr. has been a Research Scientist for the Center for Research in Water Resources, University of Texas, Austin, since 1988, and Associate Director of CRWR since 1989. He attended the University of Texas in Austin, and received his BS in Mathematics and Physics, 1965, his MA in Mathematics, 1967, and his Ph.D. in Civil Engineering (Geophysical Fluid Dynamics), 1975. His special expertise includes coastal oceanography (physical), stream and river water quality analysis, dynamic meteorology, surface-water hydrology, circulation and transport in bays and estuaries, lake and reservoir hydromechanics and temperature structure, and modeling of rivers, lakes and estuaries, to name but a few.

Abstracts of Presentations

WATER QUALITY IN THE LOWER NECHES RIVER

Dennis Becker
Lower Neches Valley Authority

BASIN OVERVIEW

The Neches River Basin has an overall length of 210 miles and a maximum width of about 70 miles, with a drainage area of approximately 10,000 square miles. It rises near Canton in Van Zandt County and empties into Sabine Lake near Port Arthur. At that point it is joined by the Sabine River and their commingled waters discharge through Sabine Lake into the Gulf of Mexico.

The Angelina River is the Neches' largest tributary, with its confluence located near river mile 126. Other significant tributaries include Village Creek and Pine Island Bayou, located in the Lower Neches, which merge below river mile 40.

Blessed with an abundance of rainfall, ranging from approximately 40 inches per year at its headwaters to 53 inches per year at its mouth, the mean annual runoff of the Neches River is approximately 7.5 million acre-feet. The Lower Neches Basin is generally flat and heavily forested with several units of the Big Thicket National Preserve located within its boundaries.

This paper will consider water quality issues affecting the lower portion of the Neches River Basin below river mile 40. With the exception of nutrients, all parameters were compared to the latest edition of the Texas Surface Water Quality Standards (TSWQS). The TSWQS does not specify numerical criteria for nutrients (nitrogen and phosphorus constituents). Therefore, nutrient criteria used were developed to identify streams with significantly higher concentrations than background or natural levels.

WATER QUALITY REVIEW BY SEGMENT

The lower portion of the Neches Basin is divided into two segments, the Neches River Tidal Segment 0601, and the Neches River below B.A. Steinhagen Lake, Segment 0602.

SEGMENT 0601: NECHES RIVER TIDAL

Description: From the confluence with Sabine Lake to a point 7.0 miles upstream of IH-10 in Jefferson and Orange Counties.

The hydrology of Segment 0601 is influenced mainly by tidal exchange with Sabine Lake and the Sabine-Neches Canal at the lower end of the segment and freshwater inflows from Pine Island Bayou and the Neches River at the upper end of the segment. Texas Surface Water Quality Standards designated uses for 0601 are contact recreation and intermediate aquatic life. The tidal portion of the Neches River is highly developed, industrialized, and a busy international port with numerous domestic and industrial wastewater dischargers.

Well documented water pollution problems in 0601 have in the past been attributed mainly to the effects of municipal and industrial wastewater effluents. In the early 1970's, the tidal portion of

the Neches River was one of Texas' most polluted waterways. However, due to improvements in industrial and municipal wastewater treatment systems since the early 1980's the biochemical oxygen demand (BOD)* waste load to the Neches River has been reduced from 223,500 pounds per day in 1968 to approximately 7,700 pounds per day in 1990, a 96 percent reduction. As a result of this waste load reduction, dramatic improvements in water quality have occurred in the tidal estuary, with the Neches River experiencing far fewer water quality standards violations than in the past.

Biochemical Oxygen Demand (BOD) refers to the amount of dissolved oxygen consumed by biological processes breaking down organic matter in an effluent. Large amounts of organic waste use up large amounts of dissolved oxygen.

TABLE I
SUMMARY OF INTENSIVE STUDIES OF SEGMENT 601 - NECHES RIVER TIDAL

	Location	1996*	1987	1980	1975
	Bunns Bluff			As, Cd, Cr, Cu, Pb, Ni, Zn	
	Temple Inland				
	IH-10			As, Cr, Zn (sed)	PCBs (sed)
	Orange County-Oak				
	Meyers Bayou				As, Hg, Pb, Zn, DDE, PCB's (sed)
	above Mobil				DDE, PCBs (sed)
	below Mobil	As (sed)	dieldrin Pb (sed)	As, Cd, Cr, Cu, Pb, Ni, Cn, bis (2) As, Cr, Zn (sed)	As, Hg, Pb, Zn, DDE, PCBs (sed)
	Dupont		Cr		
	Smith Bluff			As, Cr, Zn (sed)	As, Hg, Pb, Zn (sed)
	Grays Bayou				As, Hg, Pb, Zn, DDE, PCBs (sed)
	Port Neches City Park			As, Cd, Cr, Cu, Pb, Ni, Zn, bis (2)	As, Hg, Pb, Zn (sed)
	below Star Canal			As, Zn (sed)	Cu, Pb, Mn,Ag, Zn (sed)
	SH 87	Mn (sed)	Cu Cr, Cu, Zn (sed)	As, Cd, Cr, Cu, Pb, Ni, Zn, Cn, bis (2) Cr, Cu, Zn (sed)	Cu, Pb, Mn,Ag, Zn (sed)
Notes		Toxics in wtr, sed sampled	Toxics in wtr, sed, tissue sampled	Toxics sampled in wtr, sed, aquatic As (sed) at all sites	No toxics sampled in water

(sed) = sediment
bis (2) = bis (2-ethylhexyl) phthalate
** Conclusions from the 1996 305(B) report*

Texas Natural Resource Conservation Commission (TNRCC) water quality data for 0601 collected from 1981 through 1992 for field data (temperature and pH) and conventional data (dissolved oxygen, fecal coliform and nutrients) were compared to stream criteria. This analysis revealed that fecal coliform bacteria exceeded the screening criteria of 400 colonies/100 mL in an average of 23 percent of measurements. All other parameters were within the screening criteria indicative of good water quality.

Although improvements in wastewater treatment technology have led to substantial water quality improvement, investigations of trace metal and toxics incidence and effect on the aquatic communities remain areas of high priority. Although the ability to measure trace amounts of various toxic chemicals has increased dramatically recently, the high cost of these analyses has limited collection of this type data.

Historical metals and organics data for Segment 0601 are available on a somewhat limited basis from several sources, including the 1996 State of Texas Water Quality Inventory generated by the TNRCC, commonly called the 305(B) report, TNRCC Intensive Survey data and U.S. Army Corps of Engineers dredge spoil sampling data. The results of intensive surveys performed by the TNRCC in 0601 in 1975, 1980, 1987 and conclusions from the 305(B) report are included in Table I. This table demonstrates a significant reduction in the number of priority pollutants detected over time, with the most recent 305(B) report citing only arsenic in sediment below the Mobil canal and manganese levels in sediment near SH 87 as being elevated.

The U.S. Army Corps of Engineers sampled in the segment from 1983 to 1990 during dredging operations. Metals measurements from 1983 to 1990 were for total metals and were not high compared to water quality criteria. Organics (pesticides and fertilizers) measurements from 1983 to 1990 tended to be below detection limits, with only two samples in the Sabine-Neches Canal found to exceed water quality criteria. More recent data for the period 1990 to 1995 were examined and the majority of the measurements were below the analytical detection limits and the few detections were well below water quality criteria. In the 1996 305(B) report the TNRCC ranked stream segments across the state from 1(highest priority for action) to 366 (lowest priority for action). Segment 0601 was given a state ranking of 89.

SEGMENT 0602: NECHES RIVER BELOW B.A. STEINHAGEN RESERVOIR

Description: From a point 7.0 miles upstream of IH-10 in Jefferson County to Town Bluff Dam on B.A. Steinhagen Reservoir.

This water quality segment is 88 miles in length, and is classified for contact recreation, high aquatic life and public water supply uses. The Lower Neches Valley Authority and City of Beaumont both have potable water supply intakes located within this segment.

The USGS and TNRCC have routinely

monitored water quality in this segment in the past. Water quality within this segment is normally very good, characterized by low dissolved solids and hardness, with dissolved oxygen values rarely falling below the stream standard of 5.0 mg/L. A review of TNRCC and USGS water quality data collected from 1981 through 1991 for field data and conventional parameters were compared to stream criteria for Segment 0602. This analysis indicated that all parameters were within the screening criteria indicative of good water quality.

A fish consumption advisory was issued by the Texas Department of Health for this segment on September 19, 1990. This advisory was issued as a result of dioxin contamination in all species of fish, and recommended consumption of no more than one meal, not to exceed 8 ounces, each month. The advisory was rescinded effective December 5, 1995. Further sampling indicated that the levels of dioxin in fish tissues have decreased to an acceptable level, and did not indicate any other contaminants of concern.

An analysis of the TNRCC and USGS database for the same time period was performed for most metals parameters. The results of this analysis indicated that a total of 23 percent of measurements for copper exceeded the screening criteria of 3.87 mg/L. Data were insufficient to allow an analysis for cadmium and lead. All other metals parameters were within the screening criteria indicative of good water quality.

Additionally, the 1996 305(B) report analyzed metals and organics data for the period 1989 through 1992. The report states that "although there were no violations of the cadmium in water acute criterion, the mean of samples exceeds the chronic criterion causing non-support of the aquatic life use. Manganese levels in sediments are elevated." This report gave Segment 0602 a state ranking of 88.

CONCLUSION

Water quality in the Lower Neches River has improved dramatically since the late 1970's. However, comprehensive datasets for priority pollutants for the Lower Neches Basin in general are lacking. In a number of instances the data are insufficient or the methods used to analyze the water and sediment samples are uncertain, making it difficult to thoroughly analyze the water quality or aquatic conditions.

This problem is currently being addressed by the Texas Clean Rivers Program (CRP), authorized by the Texas Legislature in 1991. The goal of this program is to provide a comprehensive, coordinated approach to water quality monitoring that will provide information to produce regional water quality assessments for each river basin statewide. The program is currently funded through fees assessed on wastewater and water rights holders. The TNRCC is charged with providing technical assistance to the regional partner (usually river authorities) in conducting and preparing a statewide summary of all individual regional assessments.

Through the CRP, the LNVA has designed a coordinated water quality monitoring program which will minimize any overlap among State, Federal, County and local agencies and increase the amount of water quality data being generated. This innovative program based on the concept of coordinated statewide monitoring will provide much needed information for prioritizing water quality problem areas, identifying hot spots, preventing further pollution and protecting areas with high water quality. Copies of the 1996 Regional Assessment of Water Quality for the Lower Neches Basin are available from the Lower Neches Valley Authority. This report includes a detailed analysis by segment of available water quality data from 1980 through 1995, and presents significant findings, goals, recommendations and the future plans of the LNVA Clean Rivers Program.

THE SABINE LAKE AREA: A REGION IN TRANSITION

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Southeast Texas and southwestern Louisiana's coastal lowlands are broken by a series of long, narrow, sand ridges, called "cheniers." A term derived from the French word *chene* of oak. Referred to as the Chenier Plain, the tract was formed by wave action pushing sand up onto the shore. Each chenier marks the position of a once active shoreline. When the Mississippi River occupied one of its western courses, clays, muds, and sands were carried westward by littoral currents, advancing the Chenier Plain as a mud coast. Interruptions in the progradation process allowed coarser particles to accumulate as a ridge. An increase in sedimentation caused the shoreline to advance leaving the conspicuous, oak-covered cheniers as the region's most impressive and continuous topographic feature. Throughout this region the shoreline is eroding rapidly, as a result beaches are often quite narrow. Consequently, low-lying areas are frequently inundated by minor storms. In Texas, Highway 87 is overwashed repeatedly and closed periodically, while Louisiana Highway 82 has been relocated because of shoreline erosion.

INTRODUCTION

The Chenier Plain/Sabine Lake region's geographic complex is a product of two distinct ingredients: one natural and the other cultural, or human. Relief, soils, landforms, subsurface geology, vegetation, climate, and other natural agents are traditionally well studied and often self-evident (Baumann and DeLaune 1982; Boesch *et al.* 1983; Baumann *et al.* 1984; Britsch and Kemp 1990; Boesch *et al.* 1994; Coleman 1966). Wetland loss is particularly well documented (Davis 1982; Turner and Cahoon 1987; Penland *et al.* 1989; Dahl 1990; Penland *et al.* 1990). Cultural elements—demography, ethnicity, economy, learned skills, acculturation and assimilation, cultural adaptation and heritage, along with historical and evolutionary change—are not observed easily (Kniffen 1936; Knipmeyer 1956). In reality, these cultural and/or social identifiers are often the foundation for the coastal zone's importance as a productive environment. Moreover, exploitation patterns cannot be explained by land characteristics alone. Many factors complicate the interpretation of land use, including people's tastes, desires, and traditions, particularly when one compares and contrasts the cultural elements of east Texas with those of Louisiana's chenier plain. Houses, fence and barn types, cattle brands, colloquialisms, foodways, land-division systems, furniture, spinning and weaving techniques, buggies, boat types, *Les Coqs Ga_ime*, farm equipment such as a grist mill (*moulin ã gru*), music, and *cafẽ noir* are the material and nonmaterial vernacular elements that serve as part of the region's cultural fabric.

Because many of these elements are vague, less fixed, intangible, and difficult to study, culture and the associated social phenomena are frequently disregarded by the policy-making community. The natural sciences are easier to quantify and incorporate into policy decisions, whereas interpreting cultural/social elements in the decision-making process can be difficult (Murdock *et al*, 1984; Gramling and Laska 1993; Seydlitz and Laska 1994). These cultural components are often considered too abstract to be a part of the decision-making process because there is often a perception that they cannot be easily explained and/or quantified. The research techniques are available to incorporate these elements into management plans; unfortunately, they have often been ignored, misunderstood, neglected or overlooked. Even so, wetland policy involves numerous issues, such as the definition of agricultural wetlands; concerns over section 404 of the Clean Water Act; how wetlands are defined and identified; various enforcement issues and concerns; mitigation banking; takings; state, tribal, local and regional roles in wetlands protection; wetlands, runoff and watershed management matters; state wetland conservation plans; wetlands acquisition and restoration; and the Corps of Engineers regulatory programs. All are valid issues. In many instances cultural attitudes are divided by the Sabine River. The state boundary is a cultural boundary as well. The Texas side of this border is strongly Spanish influenced, while Louisiana's wetlands have been influenced by *Les Acadiens*. However, there has been considerable co-mingling of these culture groups.

SETTLEMENT

From the seaward limit of the Chenier Plain to the outer edge of the uplands or prairies, the region is a highly productive ecosystem that attracts and supports a variety of marketable aquatic and avian species. Since the marshes were devoid of high land, the region's oak-covered beach ridges became the focal point of colonization. In fact, to exist in this dynamic and sometimes inhospitable environment, the population developed and utilized innovative cultural occupancy patterns, unconventional wisdom, and a tenacious will towards maximizing the area's renewable resource base. Settlements were, therefore, established to take advantage of the region's natural resources: row-crop agriculture, cattle ranging, hunting, trapping, fishing, recreation and tourism (O'Neil 1949; Detro and Davis 1974; Gary and Davis 1979).

These settlers believed Louisiana's and Texas' semi-aquatic real estate was an attractive location for their settlements. They recognized the area's ecological value and were willing to make their living by exploiting its abundant resources. Isolated from the uplands by a marsh environment described as "inhospitable" or a "wasteland," these rural centers acquired their own distinctive employment identities. On the cheniers, cultivation extended "to the back" of these natural features as far as possible. The end of cultivation was not a property line, but a contour (Detro and Davis 1974). A settlement pattern was initiated that evolved from the region's distinctive network of parallel or near-parallel beach ridges and associated wetland habitats (Coleman and Gagliano 1964; Coleman 1966; Gagliano 1970). As a result, the greater Sabine basin exhibits an ethnic and cultural uniformity that sustained an economy based on agriculture and local wetland-dependent wildlife. Initially, economies were of the subsistence type and settlements proliferated along the isolated cheniers or on the region's limited natural levees. In time, local economies became increasingly commercialized.

Each community was economically homogeneous in that all inhabitants were supported by variations of the same means of making a living. The area's farmer-trapper-fisher folk developed skills that allowed them to harvest the local aquatic and avian wildlife. Eventually improved highway access and motorized boats eliminated the necessity of living in close proximity to the lowland's agricultural, hunting, trapping, and fishing resources. Isolated settlements gave way to small service centers with highway access that attracted migrants from their isolated communities.

THE CATTLE CULTURE

The territory's ranching heritage was established in the middle to late 1800s and represents an Anglo-Texan tradition that extended into southwest Louisiana. Brahma or Zebu became the animal of choice. These dual-purpose, humped animals were well adapted to the severe weather and insect conditions of the coastal lowlands. Through natural selection, as much as planned improvements, a strain of cross-bred cattle has been developed that endure heat, withstands insects and when necessary can graze belly deep in water. Therefore, the sand and clay-core cheniers serve as land corridors and nodal points for the *vacheries*. From these homesteads cattleman gain access to the *paille fine*, oyster grass (*Spartina alterniflora*), marshhay cordgrass (*Spartina patens*) and other vegetation assemblages that serve as the region's pasture.

Between 1880 and 1930 the marsh was considered free country, so on the cheniers many "folks" raised livestock. Cattle herds roamed the open range at will. They were rounded up in the spring from sites throughout the cheniers to be shipped by stern wheelers or organized into cattle drives along the beach. This transhumance activity resulted in cattle being shipped to market to be processed for their meat, hides and tallow, made into *Tasso* (Cajun beef jerky but derived from the Spanish term *Tasajo*), or moved to new pasture. Eventually, large land owners controlled the range and many ridge dwellers, not only maintained a small herd of cattle, but also were involved with seasonal hunting and trapping occupations. Currently, the tradition continues with ranching an established part of the local culture and involves, in some cases, the third and fourth generation.

THE RENEWABLE RESOURCE BASE

Even with the wide array of resources available to the population, the force driving the harvesting activity was the local population's willingness to utilize the estuarine-dependent wildlife. Nothing in their culture precluded collecting these edible resources. Consequently, because of their desire to use all available game, the inhabitants of the cheniers developed a life-style that focused on beef, cotton, citrus waterfowl, rabbit, deer, crawfish, turtle, shrimp, oysters and a vast assortment of fish species. Gumbo, stews, jambalaya, *sauce piquant*, *boudin*, *andouille*, and head cheese became part of their diet. Distinct folk ways emerged.

Trapping

From a trapping perspective, Louisiana's subtropical marshes and swamps were ignored until the 1800s when alligator (*Alligator mississippiensis*), mink (*Mustela vison*), otter (*Lutra candensis*) and raccoon (*Procyon lotor*) were recognized as valuable hide-and fur-bearing animals. With time Louisiana's wetland habitats became North America's preeminent fur producing region. The animals responsible for this spectacular growth were the muskrat (*Ondatra zibethicus rivalicius*) and nutria (*Myocastor coypus*) (O'Neil 1949). These animals represent a multimillion dollar industry and provide employment for thousands of full and part-time trappers. In addition, the state has a controlled alligator hunt in September, when about 25,000 alligators are harvested. Moreover, more than 120 commercial alligator farms operate throughout the state. Since alligator will not breed in salt water, the chenier's brackish habitats were ideally suited for this hide-bearing animal.

To trap marsh-dependent muskrat, nutria, and alligators, the marsh was burned periodically and small ditches were methodically chopped through the wetlands, creating a massive array of watercourses (Davis 1992). Several of these channels started as small pirogue trails that allowed a trapper to effectively work the wetlands. Through repeated use, storms, and current flow, a few of these *trainasse* became larger waterways (O'Neil 1949). Nevertheless, they evolved into permanent culture traits. More importantly, the elaborate network represents the wetland's earliest large-scale canalization projects (Davis 1978; Davis 1976; Davis 1992). Despite the years when nutria were unaccepted and muskrat were not available, marsh dwellers continued trapping; it is in their blood; it is an intricate part of their culture. In their yearly employment cycle, trapping occupies December, January, and February and the Chenier Plain is recognized as one of North America's premier trapping habitats (Davis 1978).

Seafood Industry

Though wetland residents long considered the marsh low in monetary value, they always profited from an abundant seafood catch. With time and increased demand, Louisiana's seafood harvest escalated in value. Nationally, the state's seafood production is number one by weight and second in value. Consequently, four of the country's top ten fishing ports, by weight, are in Louisiana–Cameron, Dulac, Intercoastal City, and Empire/Venice. Nationwide, these ports process over a million pounds of shrimp, oysters, blue crab, and menhaden–the principal species caught (Weber *et al.* 1992).

Shrimp in Louisiana have been a source of income and a basic food item since the colonial period. Two species are taken; white and brown (*panaeus setiterus* and *P. axtecus*). Originally harvested by cast nets and haul seines, commercial fisherman now use wooden or steel-hulled power boats outfitted with an otter trawl. Although oysters are primarily a product of southeast Louisiana, beds are exploited in Lake Calcasieu and at one time along Oyster Bayou. To remove the bivalve, oyster fisherman traditionally used "tongs." The only changes in oyster techniques have been the change from sails to inboard engines and the switch from tongs to the oyster dredge. Prior to introduction of otter or shrimp trawls, Louisiana's shrimp catch was taken by seines. Cast nets are history; wooden and steel hulled boats are now outfitted to trawl coastal waters for white and Brazil (brown) shrimp (*Penaeus setiferus* and *P. aztecus*). In May, boats catch Brazilian shrimp. White are caught in the August to December season. A special license is now required to sport shrimp. These individuals can catch up to 100 pounds a day and the catch cannot be sold. Therefore, the Louisiana's shrimp resources are intensively harvested by recreational and commercial fishermen.

RECREATION

Increased leisure-time has resulted in a wetland's landscape dotted with seasonally-occupied camps, either as isolated units or clustered on the beach face. Most of these structures are self-contained units, providing sportsmen with a summer site for fishing and a winter base for hunting and trapping. More than 5 million waterfowl winter within the Chenier Plain. As a result, recreational sportsmen kill millions of waterfowl annually and have since commercial hunting was legal. Many chenier camps serve essentially one recreational interest–hunting. In order to meet the demand for hunting space, land owners initiated private and collective lease agreements. An individual who wants to hunt must, therefore, lease a tract or join a club. Leases are required to hunt or trap on privately owned marsh and can cost several thousands of dollars per year.

At the turn of the century, hunting clubs were organized to take advantage of their leased land. In some cases, these clubs controlled extensive hunting tracts, such as those of the Gulf Coast Club–later called the Vermilion Corporation–that managed 125,000 acres, more than 70% classified as wetlands (Knapp 1991). Hunting was the primary objective of the well-to-do persons interested in this club and others scattered across Louisiana's wetlands. Currently, colorful placards identify camps as "Tropical Gardens Gun Club," The Scrip 'N Scrounge Duck Club," "Carlton's Folly," or "Florence Hunting Club." Louisiana's French heritage is reflected in camps called *"C'est notre Plasir," "Chateau de Bateau," "Lagniappe,"* and *"C'est La Vie."* Whatever whimsical name is employed, these dwellings are staging points for recreational activities (Detro and Davis 1975).

The large variety of fresh and saltwater species make fishing the marsh's largest recreational activity. The sport is a year-round activity that varies with the breeding cycle, water levels, fishing pressure, and aquatic-life productivity. In talking about the advantages of catching Largemouth Bass (*Micropterus salmoides*), considered the state's number one game fish, or Speckled Trout (*Cynoscion nebulosus*), a favorite among saltwater anglers. Heavy-use periods are during the summer months when a good "speck" fisherman measures his catch by the ice chest, not stringer. A two ice chest day is considered a success holding the limit of "specs" or "reds" (*Sciaenops ocellatus*). The freshwater bass angler is always after the elusive five pound or better trophy bass. Often organized into clubs, fresh- and saltwater anglers have added new meaning to the word "rodeo." In south Louisiana it means a fishing contest that draw large numbers of entrants.

The estuarine-marsh-swamp system's nursery ground guarantees an abundant seafood supply. More than 90% of the Gulf's finfish spend part of their life-cycle within the coastal zone. Although most species are commercially exploited, recreational enthusiasts contribute more than $400 million to the local economy, with more than half a million people involved in this leisure-time activity.

Crawfish

Only two Louisiana crawfish species (*Procambarus clarkii* and *P. acutus*) are available in abundance and are of sufficient size to be harvested. These crustaceans prefer fresh to brackish water and are collected from natural water areas and cultivated ponds. But the crawfish is more than a food item in Louisiana–it is a way of life. Found in almost every ditch and harvested from large ponds, the crustacean is utilized for food, bait, income, recreation, weed control, and as a literary topic.

Eco-tourism

Since the 1970s increasing numbers of local entrepreneurs have established local marsh tours to familiarize the traveler with Louisiana's unique wetlands. Also, a number of marinas have full-time inland fishing guides that offer the occasional angler with a guided trip without the expense of a boat, trailer, motor, insurance and rods, reels and tackle. Inland fishing guides, like their offshore charter boat counterparts, are often booked for more than 200 days a year. In addition, on the cheniers bird watching is consider excellent, as these are the last stops for the migrating populations going south and the first stops returning from South America.

THE NONRENEWABLE RESOURCE BASE: OIL AND NATURAL GAS

W. Scott Heywood completed in August 1901 the first producing well in southern Louisiana–less than a year after the discovery at Spindletop near Beaumont in southeast Texas. Within months after this Texas discovery, hundreds of wells owned by at least a hundred different companies, dotted the Texas landscape. The same type of fervent exploration activity would also take place in Louisiana. Although discovered in 1901the potential reserves in south Louisiana were ignored for the more promising fields in east Texas and north Louisiana. In fact, the discovery in south Louisiana was over-shadowed by the east Texas boom–though the Jennings field showed considerable promise and was the first major discovery after Spindletop, thus joining Texas and Louisiana oil interests.

At this time, oil was being produced so rapidly that by midsummer of 1901 it sold for as little as three cents a barrel. By comparison, a cup of water in the associated boom towns cost five cents. During this time, the Spindletop fields and others in the region were characterized by a forest of derricks nestled so close together that one could step from the floor of one derrick to that of another. The landscape was a sea of wooden scaffolding erected to extract the region's subsurface mineral fluids. Production increased rapidly, so storage became a critical problem. The solution was open pits capable of storing more than 5 million barrels. Today these fields are marked by metal storage tanks, separators and gas meters (McKenzie and Davis 1994).

The industry has evolved as technology evolved. For example, recent oil and gas discoveries in deep water of the Gulf of Mexico - defined by depths greater than 1500 feet - have estimated reserves larger than Alaska's Prudhoe Bay field. To meet this deep-water technological challenge, Auger (2860 feet), Mars (2940 feet), Ram-Powell (3218) and Ursa (4285) platforms have been installed or planned. In 1994, Auger was established in more than 2800 feet of water. In less than three years, effective operating depths have nearly doubled. When Ursa comes online in mid-1999, it will operate at more than 4200 feet - 1000 feet short of a mile. Further, these aquatically-derived hydrocarbons are transported by pipeline to shore-based installations. As a result, several major pipelines make landfall on the cheniers, part of the world's largest network of offshore oil and gas pipelines that are responsible for transporting about 95% of OCS-produced oil and 100% of its natural gas (Cahoon 1989; Davis 1991).

Several coastal fields are 40 to 60 years old and have reached the end of their usefulness. Even so, using three-dimensional seismic geology and advanced horizontal drilling technology that allows a drill bit to penetrate geological formations in one or more directions, increases the chances of finding oil and/or natural gas (Cahoon 1989). This coupled with new incentives, has renewed interest in the coastal zone's prospects. Oil companies are investing millions in leasing and exploration programs. These technological innovations have lowered the costs to find hydrocarbon reserves and improved the probability of discovering these reserves (McKenzie *et al.* 1993; McKenzie and Davis 1994). The region is undergoing a mini oil boom where approximately 7 out of every 10 exploration wells drilled are finding marketable hydrocarbons. This is the reason behind the industry's cautious optimism.

The oil industry in southeast Texas and south Louisiana mirror each other. Concomitant with this rush to find oil, entrepreneurs were building up the region's refining capacity. With time, production from this region, along with readily available and convenient water transportation routes, helped establish the refining business in Orange, Beaumont and Lake Charles. These refineries have become one of the region's major industrial concerns. For more than 80 years the Beaumont corridor has influenced the local economy, providing second and third generation family members employment. In fact, the benefits provided refinery retirees contribute significantly to the local economy. This might be referred to as "gray cash." It is derived from years of service, but does not appear in any contemporary economic calculations. Nevertheless, this income supports comfortable lifestyles, stock market portfolios, rental property, matching programs for various colleges and universities and numerous other economic and charitable activities (McKenzie and Davis 1994).

Nearly a century later, the refinery complexes in Orange, Beaumont and Lake Charles are so large and require such a wide diversity of expendables and services that outside vendors meet their needs. In many cases, this silent work force allows the companies to prosper. Valves, gages, pipe, electrical supplies, safety equipment, and numerous other items (the list is as large as a small telephone directory) come from local or regional vendors. With out these sources of supplies, the companies would be hard pressed. Further, each supplier gains from the company's demands. The local labor force and tax base also benefit. It is a circle of profits, advantages, and benefits; each group benefits the other (McKenzie and Davis 1994).

CONCLUSIONS

New partnerships between the various private and public sector elements involved in the development of a management plan need to be established that focus on the multitude of problems linked directly to humankind. These include: increased public awareness; barrier island restoration and the problems associated with implementing such a plan; pipeline—location and aging consideration; systematically updating of the well-worn onshore infrastructure; logistic support considerations; land ownership issues; general liability matters connected with working in an aquatic environment; and planning and cooperation initiatives. These are a few of the public policy concerns going into the 21st century that will establish a blueprint for maintaining the viability of Louisiana's wetlands and the state's barrier islands. In essence policy makers and scientists are moving into a new era. Consequently, it is necessary to assess each and every management objective carefully. It is no longer appropriate to examine individual components separately. All elements within the system must be analyzed to insure proper management decisions. This holistic strategy will maximize the estuary's productivity and minimize changes in the barrier island's morphological character.

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OVERVIEW OF INDUSTRIAL USERS OF THE SABINE LAKE SYSTEM

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My role in this Conference is to cover the Sabine Lake waterway system and provide an overview of its importance to the local area industry and economy. The Sabine Lake waterway system includes two river systems — Neches and Sabine; the Intracoastal Waterway, the Sabine Neches Canal, and the Sabine Pass Channel; four ports — Port Arthur, Beaumont, Orange and Sabine Pass, and over 100 private terminals, marinas, fish houses, shipyards, and area docking facilities. Due to the lack of time in preparing for this presentation, I was unable to conduct an indepth inventory of the facilities and services associated with the Sabine Lake area industrial complex, and therefore had to consult government reports and solicit local industry input to describe this areas economic activities.

For reporting purposes the U.S. Corps of Engineers has established geographic boundaries for each of the local ports. These boundaries include private terminals along with public port facilities and the statistics for these ports and private terminals are combined for reporting purposes. The Port of Beaumont includes the area from the mouth of the Neches River to Trinity Industries in Beaumont (approximately 20 miles). Port of Port Arthur includes the area from Sabine Pass Harbor to the Neches River (approximately 27.7 miles). The Port of Orange includes the area from the mouth of the Neches River to the mouth of the Sabine River and upstream to old U.S. Highway 90 (16 miles) to Adams Bayou (1.6 miles) and to Cow Bayou (7.2 miles). The Port of Sabine Pass includes the area from the Gulf of Mexico to the upper end of Sabine Pass (28.4 miles). All of this area is included in my area overview of the Sabine Lake waterway system.

Port tonnage for 1994, as reported by the U.S. Corps of Engineers, for the combined ports of Beaumont, Port Arthur, Orange and Sabine Pass ranked 8th in the United States with almost 68 million tons (See Table 1). These figures reflect the tonnage for public ports as well as area private terminals. In this case it represents the entire Sabine Lake waterway system. Texas has five ports ranked in the top 30 U.S. ports by total tonnage — Houston (2), Corpus Christi (6), Port Arthur (14), Texas City (16) and Beaumont (30). The combined port tonnage for the top five Texas ports equals over 333 million tons of cargo for 1994. Table 2 shows the five top Texas ports 1994 tonnage.

Another report from the U.S. Bureau of the Census, County Business Patterns for Texas, shows the economic value of water transportation to Jefferson and Orange counties in 1993. Using a multiplier of 1.93 for payroll figures we estimated the economic value to the area's economy to be in excess of $153 million. Table 3 shows these 1993 figures for water transportation and the economic value for ship and boat building and repair as about $50 million. Combining just these two industry groups we have an estimated economic value of over $203 million for 1993.

Looking at port and terminal activities in the area the Sabine Pilots recorded in 1995, yearly totals of 1,574 vessels calling at Sabine Lake waterway system terminals and ports. In addition there were 452 vessel movements or shifts within the harbor areas during 1995. For the first four months of 1996 there were 494 vessel calls in the waterway system and 143 movements.

Regarding the barge and towing industry activities in the Sabine Lake waterway system here are some important facts generated from local industry sources:

1. There are approximately 33,000 barge movements annually which is second only to Houston.
2. Combined Houston and Sabine Lake waterway system annual movements exceeds barge movements for all other U.S. ports. (Source: Texas Waterway Operators)
3. Annual fuel purchases for barge and towing industry in the waterway system exceeds $23 million based on a total of 33 million gallons of diesel fuel at 70¢ per gallon.

4. Fleeting services in the area generate about $3 million annually based on industry estimates.
5. Bunker fuel sales for cargo vessels coming to the area ports and terminals exceed $30 million annually based on an average of 1,500 vessels per year.

Commercial fishing in Sabine Lake for 1994 shows an ex-vessel value of $427,860 with $387,665 coming from blue crab landings. The most recent estimates for sport fishing economic value (1987) shows sport fishing having a regional impact of over $18 million. The same report shows commercial fishing with a regional impact of about $6.2 million.

Table 1
1994 Total Port Tonnage — Top Ten Ports of the United States

		Million Tons
1.	Port of South Louisiana, LA	184.9
2.	Houston, TX	143.7
3.	New York, NY	126.1
4.	Baton Rouge, LA	86.2
5.	Valdez Harbor, AK	85.1
6.	Corpus Christi, TX	78.1
7.	New Orleans, LA	73.3
8.	Beaumont/Pt.Arthur/ Orange/Sabine Pass	67.8
9.	Plaquemine, LA	64.8
10.	Long Beach, CA	56.5

***Separate Rankings — 1994**
Beaumont - 30th
Port Arthur - 14th
Source: Selected U.S. Ports, U.S. Corps of Engineers

Table 2
Top Five Texas Ports — 1994 Total Tonnage

		Million Tons
1.	Houston, TX	143.7
2.	Corpus Christi, TX	78.1
3.	Port Arthur, TX	45.6
4.	Texas City, TX	44.4
5.	Beaumont, TX	21.2

Source: Selected Ports of the United States, U.S. Corps of Engineers

Table 3
1993 Water Transportation Economic Value
Jefferson and Orange Co.

Number of Establishments	Number of Employees	Payroll ($1000)	Multiplier	Economic Value ($Mill)
65	2,258	$79,270	1.93	$153.0

1993 Ship and Boat Building and Repairing Economic Value
Jefferson and Orange Co.

Number of Establishments	Number of Employees	Payroll ($1000)	Multiplier	Economic Value ($Mill)
15	855	$25,895	1.93	$50.0

Source: Bureau of the Census, County Business Patterns, Texas, 1993

CHARACTERIZATION OF FISHERY AND FISHING IN TEXAS WATER OF SABINE LAKE

Jerry M. Mambretti
Texas Parks and Wildlife Department

The Coastal Fisheries Division of the Texas Parks and Wildlife Department is mandated to collect long-term-trend fishery dependent and independent data. These data are the backbone of Coastal Fisheries ability to mange the fishery resources of Texas. Since 1977, Coastal Fisheries has generated an extensive long-term database with its highly structured monitoring programs.

In January 1986, Coastal Fisheries instigated routine biological, hydrological, and meteorological sampling in the Sabine Lake Ecosystem. During the last 11 year, Coastal Fisheries has compiled a comprehensive database which includes abundances, sizes, population dynamics, harvest, and utilization of the Sabine Lake Ecosystem. This information, resulting from over 7,000 fishery independent (bag seine, beach seine, gill net and trawl) samples and over 800 fishery dependent (access site creel) surveys, is being compiled to characterize and mange the diverse components of Sabine Lake Ecosystem's recreational and commercial interests.

TIDAL CIRCULATION IN SABINE LAKE

Peter A Mantz and Ainong Dong
Professor and Research Fellow
Lamar University

A mathematical model of Sabine Lake and its related environment was calibrated using recent water level data from 8 nearby tide stations, fresh water inflow data and several days of tidal current data. The data was chosen to represent normal astronomical conditions for a mixed tide. Significant flood and ebb currents existed for the first and last 7 hours of the diurnal tide, and the second high water caused weak flows for the intervening 11 hours . Maximum flood tidal flows of about 2 knots were found at the lower end of Sabine Lake and these decreased to about 0.2 knots in the interior. A flood eddy system was generated for 2 hours at the upper end of the Lake, and an ebb eddy system was generated about the lower end of the Lake. These systems reduced ambient flows.

INTRODUCTION

The tidal flow of water in Sabine Lake is dominated by the tidal processes emanating from the Gulf of Mexico. These tidal currents are superimposed on the fresh water flows from the surrounding catchments of the Sabine and Neches rivers, and the smaller bayous such as Taylor , Johnson and Black Bayou. Figure 1 illustrates the provenance influencing this circulation in Sabine Lake. The extent may be defined to be from several miles upstream of Beaumont and Orange (at locations where the river flow is not tidally influenced) to several miles offshore Sabine Pass (at locations where the tidal flow is not influenced by fresh water). The provenance is named the Sabine-Neches Estuary.

A first step towards understanding tidal circulation is to monitor the associated water levels at different locations in the provenance. This task has traditionally been conducted by the National Ocean Service (NOS), since the devasting hurricane centered on Galveston in the year 1901. The continuous monitoring of water levels for Sabine Lake has been conducted since 1958 at one location (Sabine Pass), and several surveys of about one month's duration each have been conducted at Sabine Lighthouse (near the Sabine Offshore station), Sabine Pass Jetty, Mesquite Point, Beaumont and Orange (NOAA, 1990). This program has recently been extended by the State of Texas under the administration of the Texas General Land Office (TGLO) and the Texas Water Development Board (TWDB). Since 1993, Lamar University at Beaumont (LUB) have installed seven additional water level gauges (Mantz, 1996). The activity is part of a joint project with NOS, TGLO, TWDB, the US Army Corps of Engineers and Texas A&M at Corpus Christi. The total program is entitled the "Texas Coastal Ocean Observation Network" (TCOON).

A second step towards understanding tidal circulation is to measure tidal current velocities at different locations. The technology for reliable, continuous current monitoring has only been recently established (Appell et al, 1994), and there is no long term data for Sabine Lake. Several short term surveys have been organised by the TWDB. For example, a four day survey of tidal currents and water levels was conducted in 1974 (Water Resources Engineers Inc., 1977), a twelve day survey in 1990 (Longley et al, 1994), and a recent four day survey in June, 1996. Tidal currents have also been measured in the Port Arthur Canal for flood and ebb tide conditions (Mantz, 1986).

Fresh water inflows to the provenance have been traditionally monitored by the United States Geological Survey (USGS). A compilation of both gauged and ungauged inflows for Sabine Lake has been made by the TWDB (Longley et al, 1994). This consists of monthly freshwater inflows for the period 1941 to 1987, and daily freshwater inflows for the period 1977 to 1987. The relevant gauged inflows were at Evadale, Village Creek and Pine Island Bayou for the Neches river, and at Ruliff for the Sabine river. The relevant ungauged inflows were hydrologically modeled by computer for the catchments downstream of the gauged flows, and for the Taylor Bayou, Keith Lake, Johnson and Black Bayou catchments.

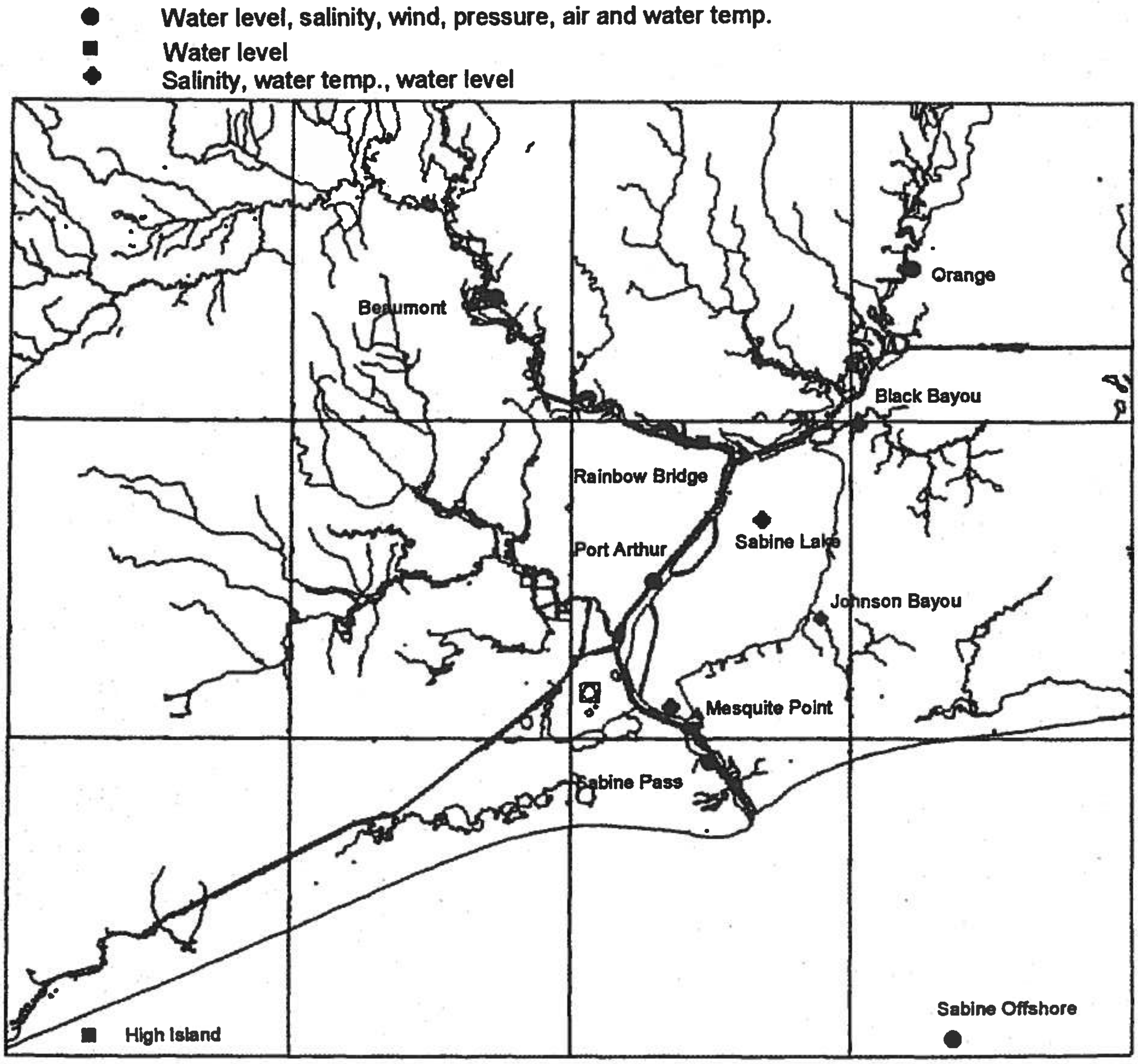

Figure 1. Environmental monitoring for Sabine Lake (from USGS 15 minute digital line graphs).

The modern scientific method is to synthesise the above data into a geographic computer model of the provenance. To date, there have been two computer codes used for modeling. The TWDB have used a depth-averaged model which is designed for flow simulation over the course of about one year (Matsumoto, 1993). In contrast, LUB have used a depth-averaged model which describes fluid friction in more detail (Gray,1976). The extra computations for the latter give a better detail for tidal circulation, and simulations can be run for several weeks.

TIDAL WATER LEVELS

Figure 1 locates the eight water level stations which have been installed in the provenance. The stations use modern instrumentation designed by the NOS (Edwing, 1991). Water level is measured, with an accuracy of about one millimeter, every second for 3 minutes in a 6 minute cycle to give an average and standard deviation. The data is then transmitted every 3 hours via GOES (Geostationary Orbital Earth Satellite) to an NOS database. The latter is accessed hourly via Internet from LUB, and plotted automically as in Figure 2. Direct communication with the stations is maintained by cellular or land telephones. And each station uses a telephone speech modem to report verbally the most recent measurements .

The tide at all locations has a conspicuous diurnal inequality in the two low water levels (Figure 2) . It is therefore classified as a mixed tide (Hicks, 1989). As the tide progresses from Sabine Offshore (a station about 32km SE of Sabine Pass) to Orange and Beaumont, both the amplitude and degree of mixing decrease. This fact has been quantified by calculating the astronomical constituents of an annual tide series (Dong, 1995). Figure 3 shows the results of a harmonic analysis at three stations for the year 1994. There are 5 major constituents which influence the signal, namely the annual and semi- annual solar constituents (Sa and Ssa), the diurnal lunar and lunisolar constituents (O1 and K1), and the principal lunar semi-diurnal constituent (M2). The S2 semi-diurnal solar constituent was relatively small, since the Gulf of Mexico is an almost enclosed body of water which is of much smaller mass than other oceans in the World . The average annual tide may be quantified by considering the ratio of diurnal components to semi-diurnal com-

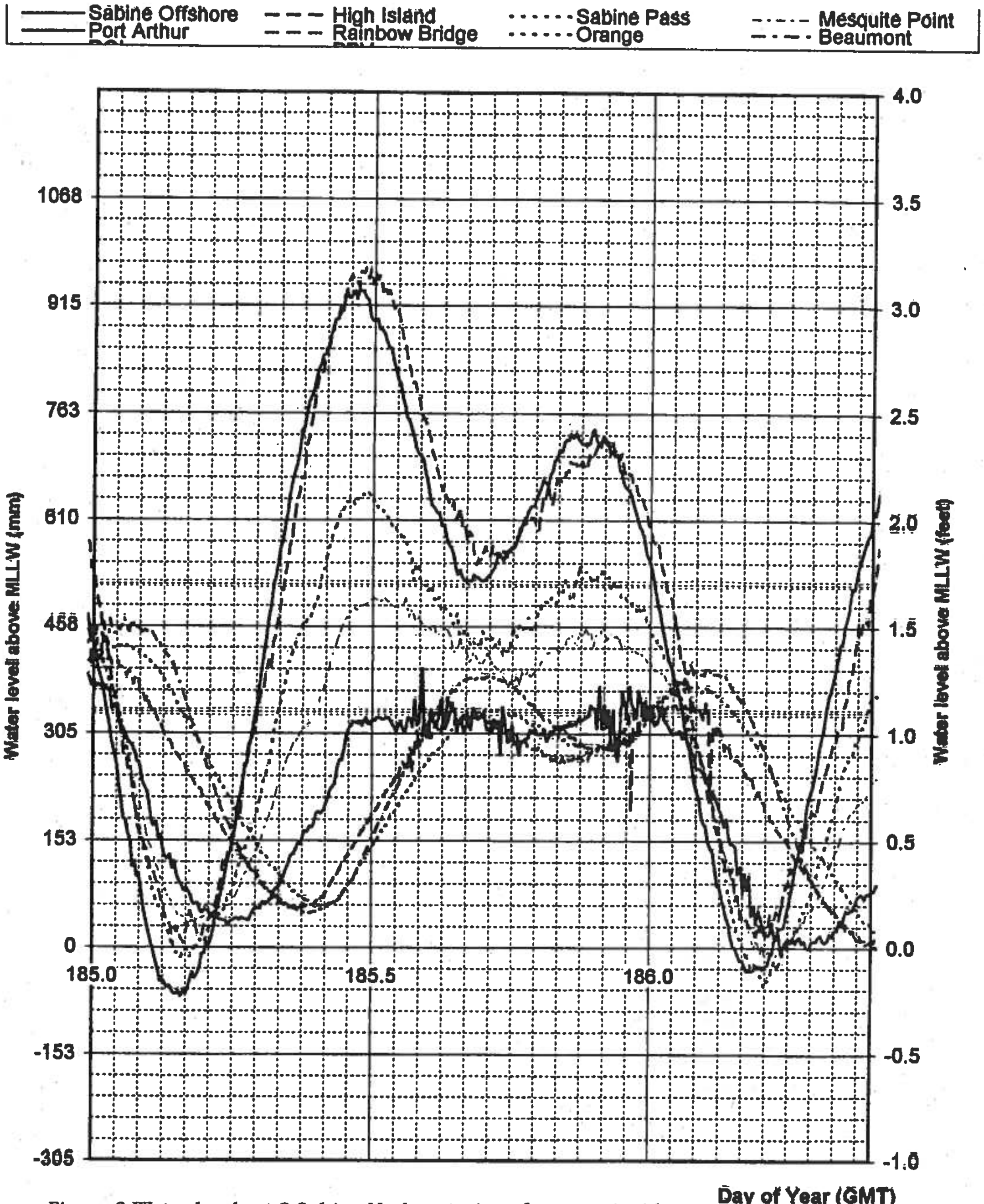

Figure 2. Water levels at 8 Sabine-Neches stations for a tropic tide.

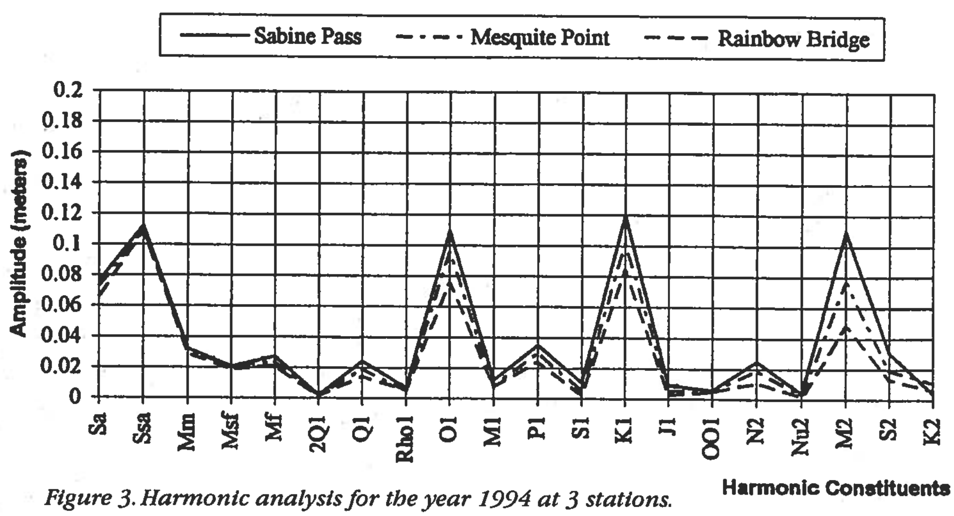

Figure 3. Harmonic analysis for the year 1994 at 3 stations.

ponents (K1+O1/M2+S2). This varied from 1.7 offshore to 2.3 inland, indicating that the tide was dominantly diurnal, though mixed.

The monthly variation of water levels for May, 1996 was chosen to illustrate normal astronomical tides with minimum meteorological interference (Figure 4). Changes in the tide range(diurnal highest to lowest water level) were mainly due to changes in the Moon's declination (O1 and K1), and produced two cycles for the lunar orbital period of 27.3 days. The tide range varied from about 1000mm to 300mm for Sabine Offshore, and 400mm to 200mm for Beaumont and Orange. At maximum declination, when the moon was over one of the tropics (days 127 and 141) , the mixed "tropic" tide was apparent. And at zero declination, when the moon was over the equator (days 134 and 148), the "equatorial" tide was almost semi-diurnal (M2). Note that these normal water levels are often raised by tropical storm surges in the Summer, and lowered by Northerly depressions in the Winter (Mantz and Dong, 1992).

The NOS method of "tide-by-tide" analysis was used to summarise this localised water level data (NOAA tide tables, 1995). Sabine Offshore was used as a base station whose high water occured at zero time and whose tide range was unity . By analysing the times and heights of consecutive high and low waters for each station, average values were derived to enable a quantitative picture of the tide's progress. Figure 5 illustrates these tide station differences, as derived from the recent data. A generalised view of the characteristics are now given.

The time difference from Sabine Offshore to Mesquite Point was about one hour (about 40km distance), the time difference to Rainbow Bridge was about 4 hours (about 70km distance), and to Orange it was about 5 hours (about 90km distance). Sabine Lake therefore slowed the tidal progress, and this was mainly due to the shallower flow. The range difference showed that the offshore tide had lost about 50 percent of its amplitude at Mesquite Point, about 55 percent at Rainbow Bridge, after which it was almost constant to Orange and Beaumont . Since the square of the tide range (H^2) is proportional to its gravitational

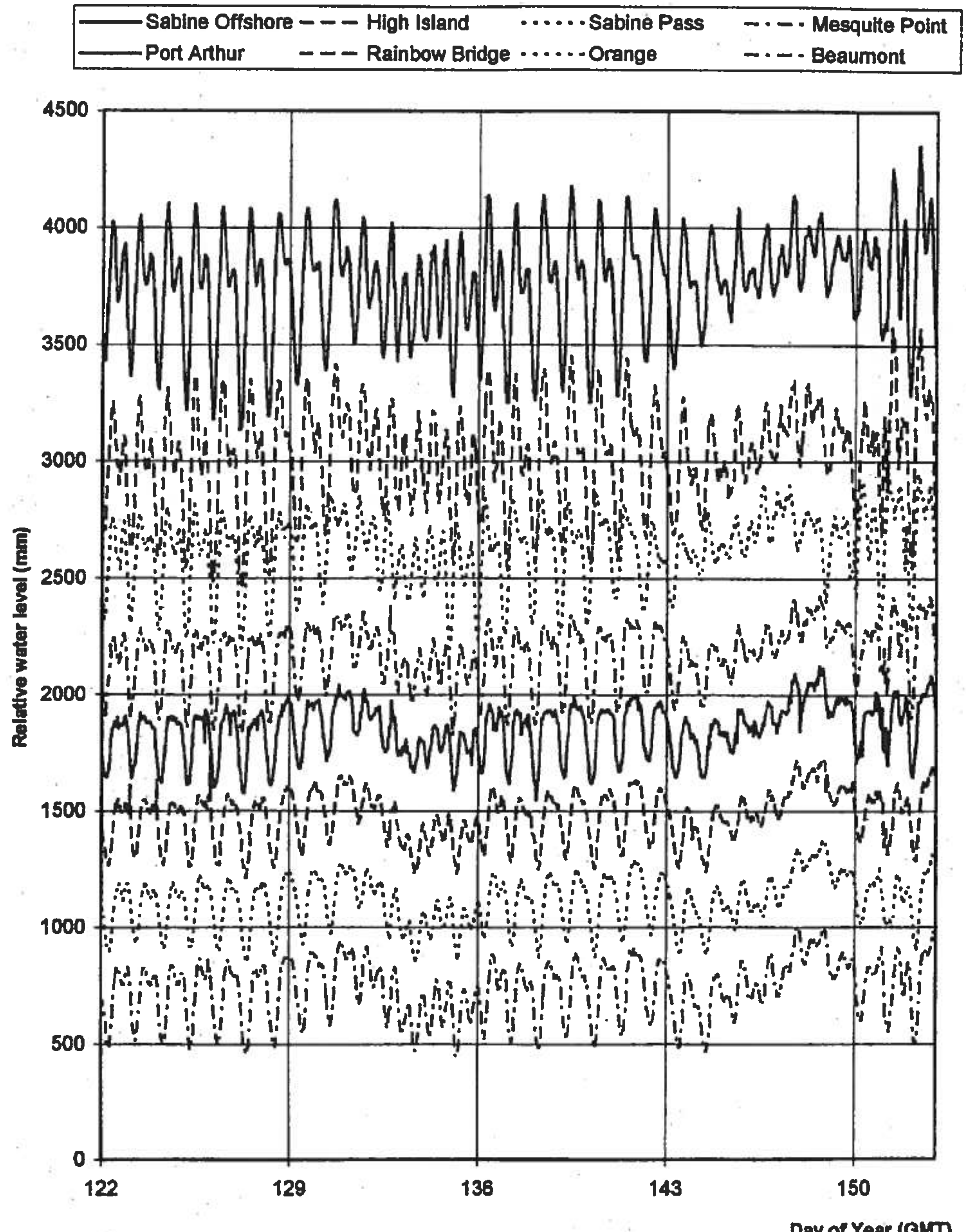

Figure 4. Water levels for May 1996.

energy, about 75 percent of the energy was lost in Sabine Pass. This was generally due to the relatively high fluid friction of the constricted and faster flow.

The depths on nautical charts are referenced to the average Mean Lower Low Water level (MLLW), since that datum gives a practical minimum working depth for navigation. Accordingly, Figure 5 shows mean tidal level (MTL) above datum and mean higher high water (MHHW) above datum as examples of normal tide levels.

TIDAL CIRCULATION

The mathematical model chosen to visualise the tidal circulation used the hydrodynamic equations of momentum and continuity with small areas of the provenance (called finite elements). The equations were solved for each element, and the solution was iterated from the boundary conditions imposed at the provenance extremities. For the Sabine-Neches estuary, the boundary conditions were the fresh water inflows at Beaumont and Orange, and the tidal water levels at Sabine Offshore. (Fresh water inflows from the smaller catchments have not yet been modeled, since they are usually a small percentage of the river flows). The unknown quantities in this depth averaged model were the channel boundary friction, and the lateral fluid friction caused by eddying within the

Place	Position		Time Diff.		Height Diff.		Ranges	MLLW	MTL	MHHW
			High	Low	High	Low			Above	Above
	Latitude	Longi.	Water	Water	Water	Water	Diurnal	Datum	Datum	Datum
	North	West	h m	h m	ratio	ratio	mm	mm	mm	mm
Sabine Offshore	29°28'	93°43'	0 0	0 0	1	1	590	0	427	817
High Island	29°32.'3	94°23.'1	0 24	0 0	0.87	0.84	490	0	406	734
Sabine Jetty	29°39'	93°50'	0 5	0 0	0.96	0.96	528	0	—	—
Sabine Pass	29°43.'8	93°53.'2	0 31	0 22	0.62	0.77	314	0	305	494
Mesquite Point	29°46'	93°53.'7	0 58	0 44	0.48	0.59	183	0	239	377
Rainbow Bridge	29°59.'2	93°51.'2	3 55	4 11	0.34	0.46	163	0	171	264
Orange	30°05.'9	93°43.'3	5 7	4 41	0.36	0.48	186	0	184	282
Beaumont	30°05.'7	94°05.'6	5 31	5 9	0.37	0.47	177	0	171	295

Note: 1. *Sabine Pass was used as the refernce station.*
2. *The table is based on a tide-by-tide analysis and datum analysis. Sabine Offshore is based on the month of February, 1996. The remaining gauges are based on the month of July, 1994.*
3. *Sabine Pass and Sabine Jetty constants were obtained from the NOAA Tide Tables, 1994.*

Figure 5.Tidal Differences on Sabine Offshore for the Sabine-Neches Estuary

flow. Calibration of the model was achieved by varying these quantities until the modeled water levels at all stations were equal to those measured.

The month of May, 1996 was chosen for the present simulation, since there exists the maximum amount of data for calibration and there was no major meteorological disturbances (Figure 4). The model was then tested for predicting circulation, by comparing current velocity results at different locations with those surveyed by TWDB in 1990. A close correspondence was obtained, and only small changes of friction coefficients were necessary from those used in past simulations (Dong, 1995).

A tide is a very long wave that behaves as a shallow water wave, even in the oceans. Its theoretical speed of propagation (c) is given by the relation $c = (gd)^{0.5}$, provided d is constant, and the flow is irrotational. A physical insight may be obtained from the model by comparing the theoretical tide wave speeds with speeds calculated by following a constant tidal level in the model. Figure 6 shows the comparison for the different reaches between the tide stations. Beginning upstream, the theoretical speeds were closely matched for the Rainbow to Beaumont and Rainbow to Orange reaches. The modeled speeds were halved for the Mesquite to Rainbow reach whether the flow was via the Lake or the Ship channel. And the modeled speeds were significantly reduced in Sabine Pass. The results were consistent with the fact that there was considerable energy loss due to flow rotation (eddying) in Sabine Pass, and minimal energy loss in the slower flows up estuary. The comparison can not be made offshore, since tides in the Gulf of Mexico are also influenced by the Coriolis force to produce an amphidromic system which gives much higher speeds of rotational propagation (Bearman, 1989).

The general pattern of flood flow into Sabine Lake is illustrated for a tropic tide using velocity vectors in Figure 7. As expected, the tidal velocities in Sabine Pass were much larger and of more varied direction than elsewhere. The maximum flood current increased from about 1.8 knots in Sabine Pass to 1.9 knots at the Mesquite Point constriction, then decreased to about 0.2 knots as the Lake expanded to constant width. General flow directions were mainly in reverse for ebb flows (Figure 8) . However, the maximum ebb flow currents were less, being 0.1 knots for Sabine Lake, 1.7 knots for Mesquite Point and 1.5 knots for Sabine Pass. Note that significant flood and ebb currents only exist for the first and last 7 hours of the diurnal tide, since the second, intervening high water causes almost slack water for about 11 hours (Figure 2).

During early flood tide, there was a significant large scale, clockwise eddy system at the upper end of Sabine Lake (Figure 9). This was caused by the shallow lake depth. As quantified in Figure 6, the increasing tide level propagated more quickly in the deeper ship channel. From the tidal differences of Figure

Reach	Modeled (m/s)	Theoretical (m/s)	Depth (m)
Sabine Offshore to Sabine Pass	N/A	N/A	12.19
Sabine Jetty to Sabine Pass	2.92	10.94	12.19
Sabine Pass to Mesquire Point	2.45	10.94	12.19
Mesquite Point to Bethlehem Steel Drydock	5.51	10.94	12.19
Sabine Lake	1.88	4.2	1.80
Rainbow Bridge to Beaumont	9.20	10.94	12.19
Rainbow Bridge to Orange	9.88	10.94	12.19

Note: The modeled tide wave speed was calculated by following a constant water level in the reach. The theroretical tide wave speed was that of a shallow water gravitational wave.

Figure 6: Summary of Wave Speeds (meter/sec)

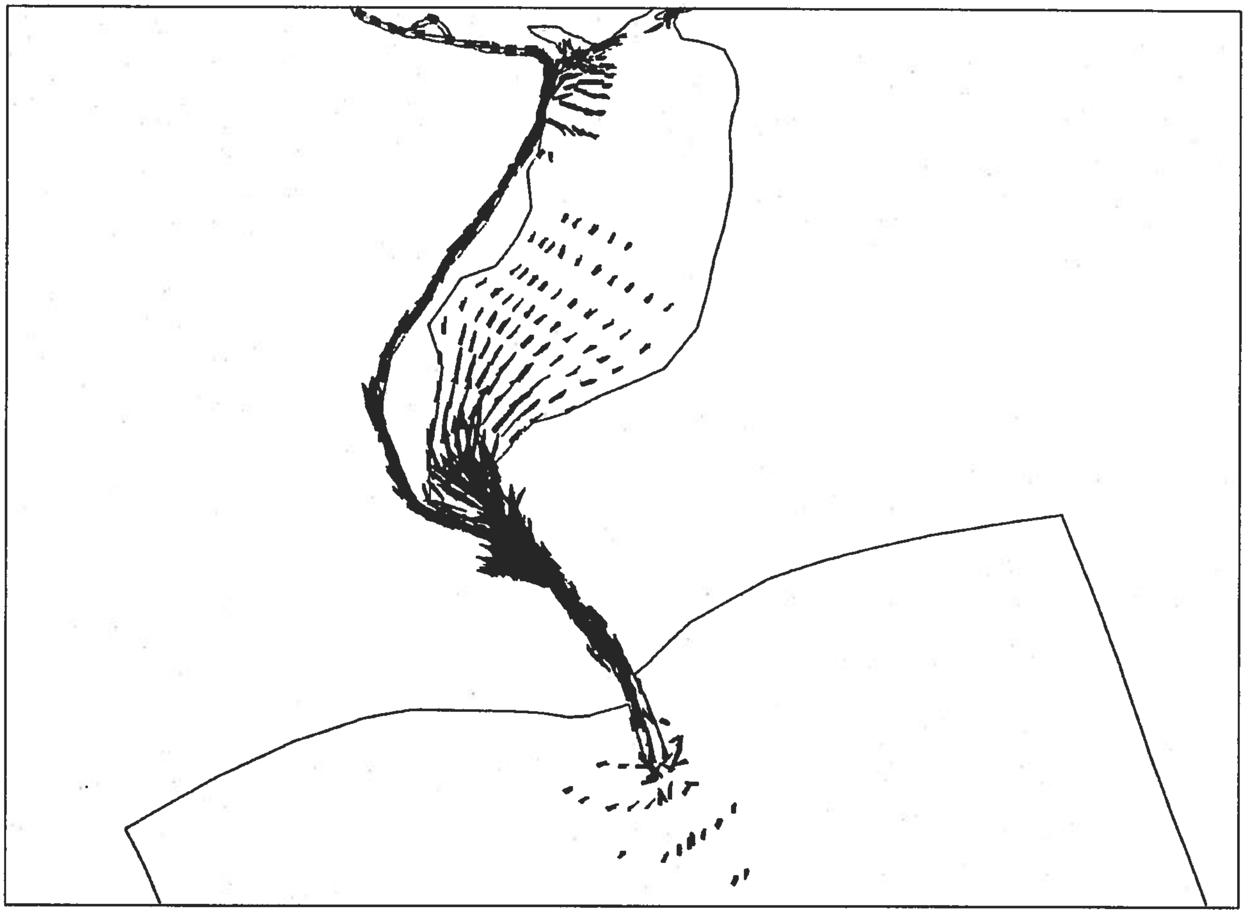

Figure 7. Early flood circulation into Sabine Lake.

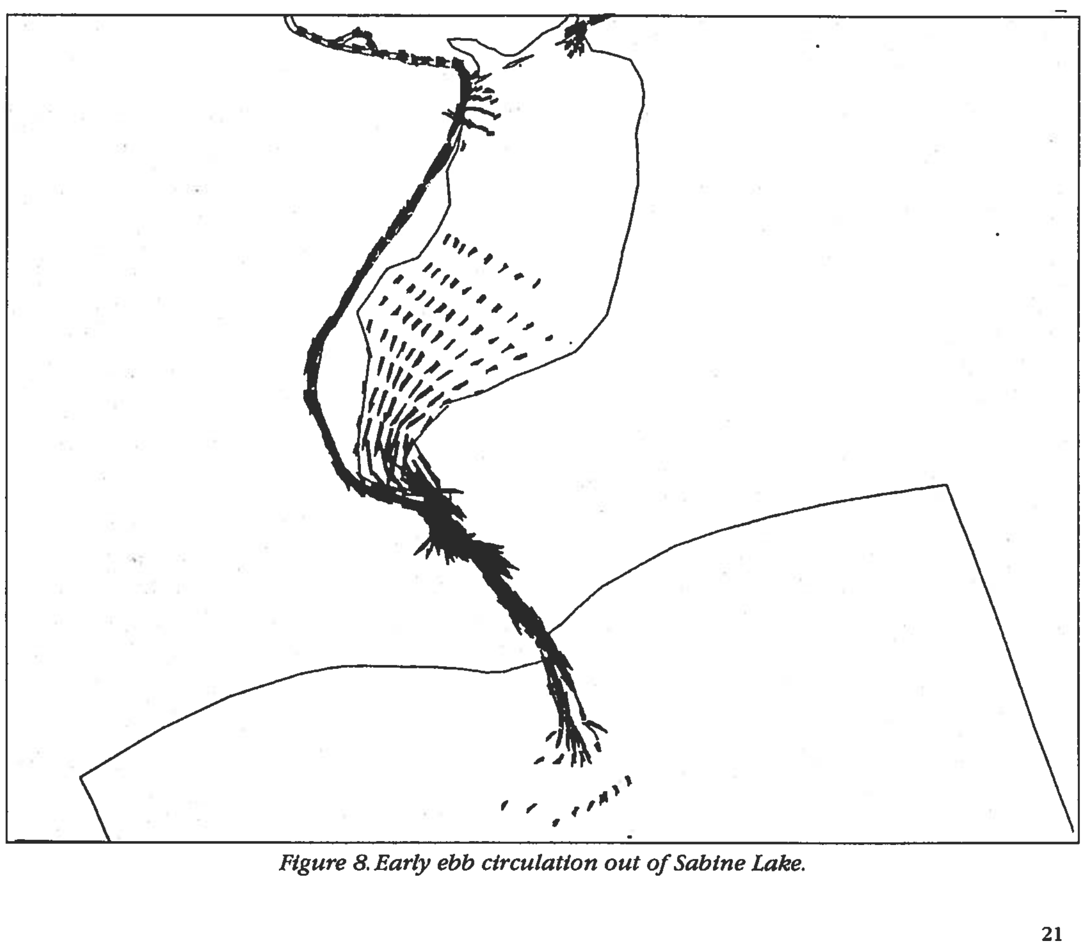

Figure 8. Early ebb circulation out of Sabine Lake.

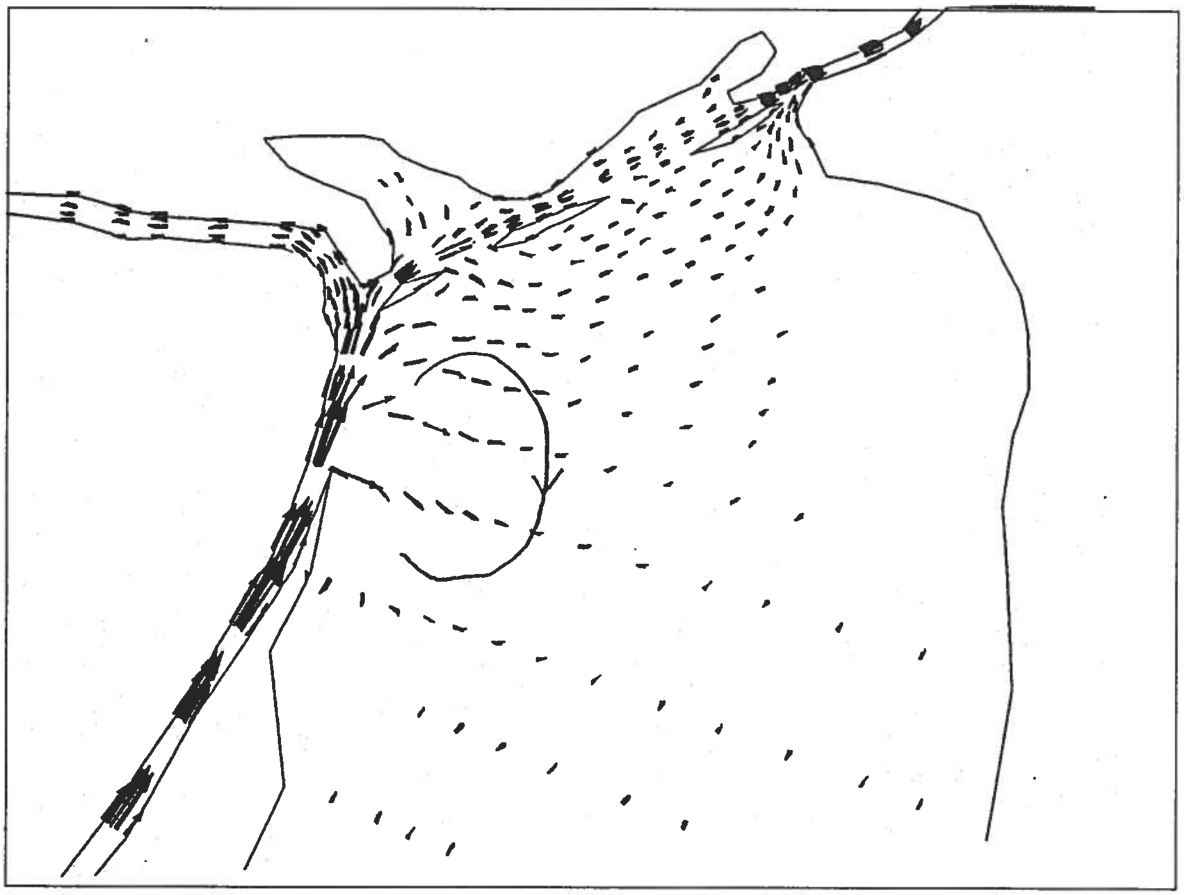

Figure 9. Flood eddy system in Upper Sabine Lake

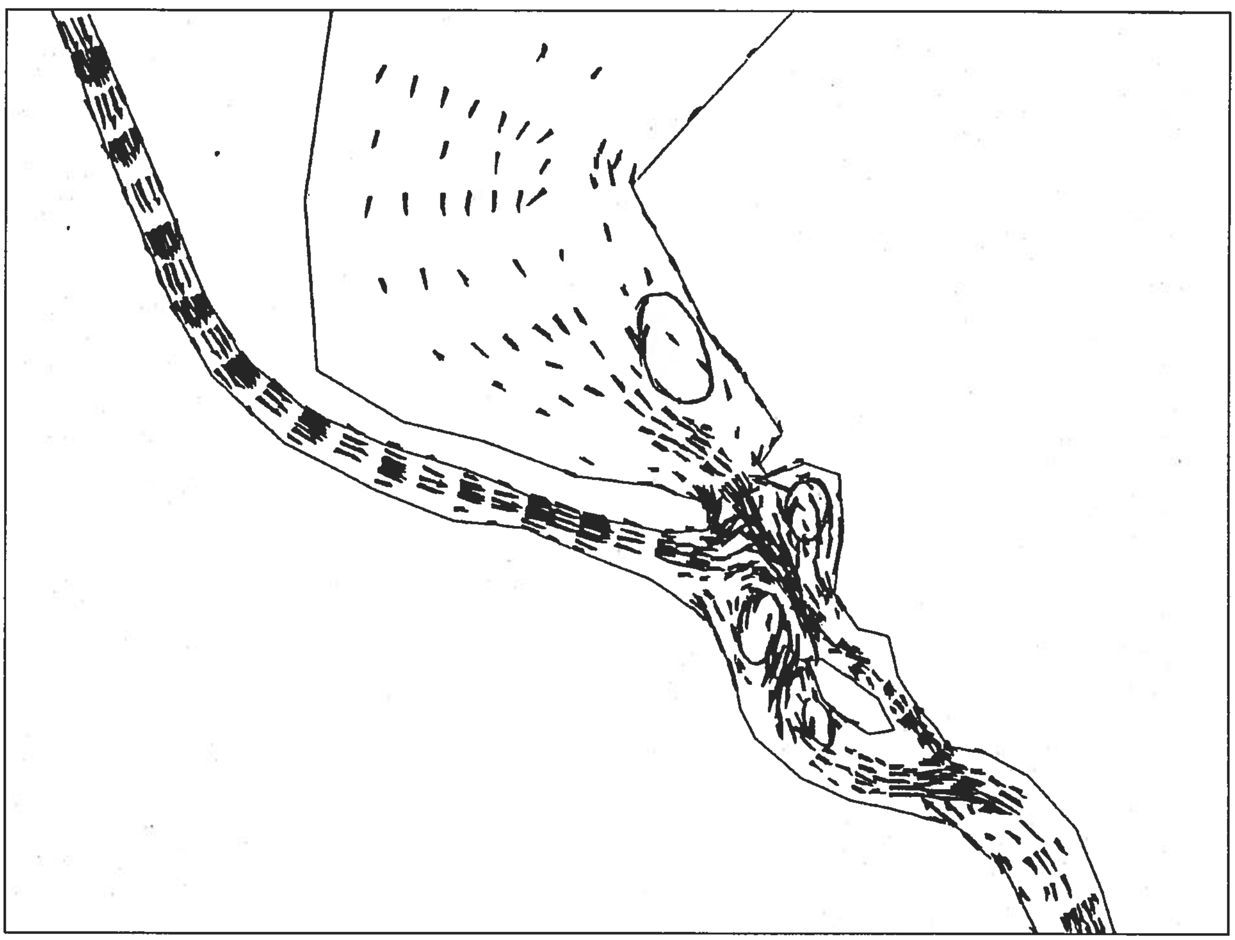

Figure 10. Ebb eddy system in Lower Sabine Lake and Sabine Pass

5, the flood tide took about one hour to reach Mesquite Point from Sabine Offshore. It then took about 3 hours to reach Rainbow Bridge. Since the travel time from Mesquite Point to the top of Pleasure Island via the ship channel was about one hour, the tide flooded into Sabine Lake at this point for about 2 hours. When a common level was reached between the Lake and the ship channel, the tide then progressed up the Sabine and Neches rivers.

During early ebb tides, the same effect caused flows through Mesquite Point to be higher than predicted for the first two hours. However , a more complex system of large scale eddies were generated (Figure 10). The rapid change of flow direction and convergence at the lower end of Sabine Lake caused flow separation near the eastern shore. At least 3 more stationary eddy systems were also generated south of Mesquite Point in Sabine Pass. These large scale systems dissipated considerable flow energy, and explain why maximum ebb velocities are less than maximum flood velocities.

It is finally noted that these preliminary studies apply only to a normal mixed tide with minimal meteorological forcing. The inevitable increase in circulation for positive and negative tidal surge conditions, wind stress and river flood flows will be examined in the future.

ACKNOWLEDGMENTS

The tide monitoring program (TCOON) is supported by a Research Grant from the State of Texas, under the administration of the Texas General Land Office and the Texas Water Development Board. A significant contribution to the program has also been made by the US Army Corps of Engineers (Galveston District). This continuing data analysis is being supported by the Trans-Texas Water Program Southeast Area Study, under the administration of the Consulting Engineering Company, Brown & Root Inc. The authors wish to thank these agencies for their support.

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EXISTING ECOSYSTEM MANAGEMENT SYSTEMS PROTECTING THE COASTAL WETLANDS IN THE CALCASIEU/SABINE RIVER BASIN

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USDA - Natural Resources Conservation Service

The Calcasieu/Sabine River Basin is located in Southwest Louisiana. The river basin has approximately 230,000 acres of coastal wetlands in Calcasieu and Cameron Parishes.

The coastal wetlands within the basin historically consisted of a vast unbroken stand of emergent vegetation ranging in salinity from fresh to brackish. Most of the brackish marshes bordered Calcasieu and Sabine Lakes. The basin was subjected to natural disturbances such as storms, fires, freezes, droughts and animal eat outs. However, the basin remained virtually unbroken, the ecosystem structure and the ecological processes continued to function making the system resistant to the temporary disturbances until the 1940s and 1950s.

The construction of several major navigation channels, such as the Calcasieu Ship Channel, the Gulf Intracoastal Waterway (GIWW) and the Sabine/Neches Waterway allowed Gulf strength saltwater to circulate around the perimeter of the entire basin. The single most significant event affecting the basin has been the construction of the Calcasieu Ship Channel in 1941. Since that time, the area within the Calcasieu/Sabine River Basin has experienced accelerated marsh deterioration and conversion to shallow open water. During the 50 year period from 1933 to 1983, approximately 76,000 acres of vegetative marsh has been converted to open water. Most of the conversion occurred during the period from 1958 to 1978. For example, 81 percent of the marshes in the Black Lake area was converted to open water during this period.

Other hydrologic modifications have also played a significant role influencing marsh loss in the river basin. Many miles of ingress and egress canals have been constructed for petroleum exploration, hunting, fishing and trapping resulting in expanded tidal fluctuations, increased water depths and saltwater intrusion into most of the interior marshes that were historically fresh or intermediate. Some of the larger canals include the Alkali Ditch, the North Starks Canal, the Starks Central Canal, the South Starks Canal, the Willow Bayou Canal, the Back Ridge Canal, the Burton Sutton Canal and the Beach Canal.

Landowners and managers are combating the wetland loss with the use of both structural and vegetative methods. The basin is more activity managed along Calcasieu Lake than along Sabine Lake. The high salinity water transported by the Sabine/Neches Waterway is buffer with fresh water discharges from reservoirs on the Neches and Sabine Rivers. However, saltwater transported upstream by the Calcasieu Ship Channel remains unbuffered except during high rainfall years, consequently has a more significant negative impact on its surrounding marshes.

Hydrologic management of the marshes in the Calcasieu\Sabine River Basin area is achieved by both passive and actively managed structures.

Some basic concepts of hydrologic management are:

- At locations along the boundaries of a managed area where saltwater intrusion is a factor the management scheme is to allow saltwater to enter and exit the marsh at the same location and prevent a circulation of saltwater through the area. One way in and the same way out.
- At locations along the boundaries where freshwater is entering a marsh the management scheme is to allow fresh water to enter the marsh at one location and flow through the marsh. One way in and another way out.
- At locations along the boundaries where structures are protecting a fresh marsh from saltwater influence the management scheme is to block saltwater from entering the area. Only one way flowing out.
- Hard structures (levees, and weirs) are generally used along the boundaries, however, depending on the size of the area a series of soft barriers (vegetation,

wave stilling fences, and terraces) may be installed to reduce tidal fluctuations and mimic more historic hydrology.
- Water control structures should be designed to with sufficient outflow capacity to prevent ponding during high rainfall events or tidal surges.

In the Calcasieu/Sabine River Basin, high salinity water enters the basin from three major sources: the Calcasieu Ship Channel, the Sabine\Neches Waterway and from over topping of the beach rim along the Gulf of Mexico shoreline. In 1990, a consortium of local, state and federal agencies made an inventory of water control structures along the perimeter and interior of the basin. They located one hundred and seventy-four structures. Examples and descriptions of existing and new structures installed since 1990 for controlling saltwater intrusion and tidal fluctuations are:

Locations of water exchange points on the east side of the basin are:

La. Highway 27 located along the east boundary running north to south from the GIWW to Holly Beach and La. Highway 82 running from the Calcasieu Ship Channel to Sabine Pass along the south boundary form barriers along the east and south perimeter of the basin. The openings under La. Highway 27 include Ellendar Bridge over GIWW, bridges at Kelso Bayou, Kayo Bayou, Long Point Bayou, Hog Island Gully, West Cove Canal, Second Bayou and First Bayou, structures in Headquarters Canal and just north of Holly Beach. The water control structure under La. Highway 82 at the Calcasieu Ship Channel.

A short description of structures located along the east side of the basin are:

The structure under La. Highway 82 at the Calcasieu Ship Channel is a three barrel structure. Each barrel is a 48" in diameter aluminum pipe, equipped with a flapgate on the outside and a variable crest stoplog header on the inside. The stoplogs are set 6" below marsh level and the structure allows only one-way flow into the ship channel.

The structure under La. Highway 27 at Holly Beach, La. is a two barrel structure. Each barrel is a 48" in diameter aluminum pipe, equipped with a flapgate on the outside and a variable crest stoplog header on the inside. The stoplogs are set at marsh level and the structure allows only one-way flow into the roadside ditch along La. Hwy 82.

The structure at First Bayou is a bulkhead structure with two 7ft X 5ft bays. Each bay has a variable crest stoplog header on the highway side and flapgates on the Mudd Lake side. The stoplogs are set at 6" below marsh level and the flapgates locked open. The structure is managed so that water can flow both ways (in and out) until salinity level reach or exceed 7 parts per thousand (ppt) in the road ditch west of La. Hwy 27.

The structures at Hog Island Gully and West Cove Canal are both fixed crest weir structures with radial arm tainter gates. The Hog Island Gully structure has a 7' wide gate and the West Cove Canal structure has a 11' wide gate. The gates for both structures remain in an open position until the water salinity reach or exceed 12 ppt in Brown Lake (on the north end Sabine National Wildlife Refuge) for the Hog Island Gully Structure and 12 ppt in Back Ridge Canal for the West Cove Canal Structure.

The structure at Headquarters Canal is a single barrel structure. The barrel is a 48" in diameter aluminum pipe equipped with a flapgate on the outside and sluice gate on the inside. The gates remain in an open position until the water salinity reach or exceed 12 ppt in Brown Lake.

All three structures, West Cove Canal, Hog Island Gully and Headquarters Canal structures, are presently being redesigned and are to be replaced in 1997. The new structures will have more capacity to remove excess rainwater and prevent saltwater intrusion during period of extreme high tides. These periods typically occur the spring months.

The Rycade Canal structure is a bulkhead structure with seven 5' wide bays. Each bay is equipped with a variable crest, stoplog weir and an exterior (Black Lake side) flap gate. The structure allows controlled flows between Black Lake and the interior marsh. The flap gates are allowed to operate when water levels in the interior are above marsh level and/or when salinity's at the structure reach or exceed 5 ppt. The management objectives of the structure are to reduce water level fluctuations and water circulation patterns that encourage saltwater intrusion and tidal scouring as well as re-establish historic hydrologic boundaries.

A short description of structures located along the east side of the basin are:

The Greys Ditch levee/cattle walkway running north to south from the Pines Ridge to Johnsons Bayou form a barrier along the east bank of Sabine Lake. There are two opening through the levee, one at an unnamed bayou approximately 1 1/2 miles south of the Pines Ridge and one at Willow Bayou.

Two structures are located along the western side of the river basin boundary, one in deep bayou and the other in South Starks Canal.

The structure in Deep Bayou is a two barrel structure. Each barrel is a 36" in diameter aluminum pipe equipped with a variable crest stoplog header on the inside and a flapgate on the exterior. The management scheme is to allow one way flow out of Deep Bayou into Johnsons Bayou.

The structure in South Starks Canal just east of the Cameron Meadows Oil Field is a three barrel structure. Each barrel is a 48" in diameter aluminum pipe, equipped with a flapgate and a variable crest stoplog header. The structure is operated to allow one way flow to the east.

There are no other known structures in any of the other bayous entering into Sabine Lake. The bayous include Lighthouse Bayou, B Fourge Bayou, Greens Bayou, Madame Johnsons Bayou, Johnsons Bayou, Willow Bayou and Black Bayou. The marshes along the Sabine Lake side of the river basin area appear to be healthy and were not being adversity affected by saltwater intrusion when the Calcasieu/Sabine Cooperative River basin Study was completed.

There are several individual management units within the Calcasieu/Sabine River Basin. Some of the units include Pool 3A on Sabine National Wildlife Refuge, Mudd Lake Management Unit and East Black Lake Management Unit.

Pool 3A is managed as a fresh water marsh. The unit is protected with levees on all sides and two fixed crest weirs that allow one-way flow out.

Mudd Lake Management Unit is managed as a brackish marsh. The unit is protected by levees on the east and south, by La. Hwy 27 on the west and an oil field road on the north. The unit has several water control structures. Some of the structures are designed with vertical slots in the variable crest stoplog headers to provide for ingress and egress of marine organisms throughout the entire water column while reducing excessive tidal fluctuations. All flows into the unit is prevented when water salinity reaches or exceeds 15 ppt.

East Black Lake Management Unit is managed as a brackish/intermediate marsh. The unit is protect with levees on all sides and three water control structures. Additional structures are planned to be installed on the east side of the unit to allow water exchange with Black Lake. All inflow into the unit is prevented when water salinity reaches or exceeds 5 ppt.

The marshes within the Calcasieu/Sabine River Basin, as a whole, have been improving health wise over the pass few years. The improvement in the basin can be attributed to above average rainfall and stabilization of tidal fluctuations and water salinity. If water salinity in Sabine Lake is allowed to increase to the levels found in Calcasieu Lake, the perimeter water exchange points will need to be managed similarly to the perimeter management found on the Calcasieu Lake side of the basin. If the ecological processes are to continue to function in the river basin we must continue to stabilize tidal fluctuations, and moderate salinity fluctuations along the boundaries and maintain a fresh water head in the interior.

A CONCEPTUAL ECOSYSTEM MODEL FOR SABINE LAKE

Robert W. McFarlane
McFarlane & Associates

Sabine Lake is exceptional among the seven estuarine ecosystems in Texas. It has the smallest surface area (17,798 ha) and volume (0.326 km^3) but the largest surrounding marshland (13,760 ha), nearly as large as the lake (Armstrong 1987). It receives the greatest precipitation (151.7 cm/yr) and experiences the least evaporation (112.4 cm/yr). It is the only estuary in Texas with a landlocked channel to the sea. It receives the greatest amount of freshwater inflow (16.1 km^3/yr) and greatest yield for its drainage area (3004 m^3/ha). It has the lowest annual average salinity (2.3 ppt). It receives the highest areal loading of nutrients (carbon 672, nitrogen 55, phosphorus 6.8 g/m^2). It may be the Texas estuary most affected by human activity.

The dynamics of estuarine ecosystems result from complex interactions between physical, chemical and biotic components of the environment (Gosselink et al. 1979, Dardeau et al. 1992, Day et al. 1989, Ward & Montague 1996). Conceptual models of complex systems can be useful management tools if they identify the critical components of the ecosystem and demonstrate the important, and ofter overlooked, linkages between these components (McFarlane 1993). The dominant characteristic of estuarine ecosystems is constant change. Ecological concepts such as *equilibrium* and *stability* have little relevance when applied to estuaries. The most fundamental change agents are **solar radiation** and **gravity.** The absorption of 50% of solar radiation reaching earth results in differential heating of the planet (diurnal-nocturnal and equatorial-pole gradients) that drives wind patterns and ocean currents. Radiation on the Gulf of Mexico evaporates surface water which the predominantly southerly winds carry over the continent where precipitation falls on the watershed. Solar radiation also facilitates both aquatic and terrestrial photosynthesis vital to the estuary food web. Gravity ensures that both surface runoff and groundwater, and their associated particles and chemicals, move steadily downhill to the lake. Gravitational attraction of the sun and moon, modulated by their relative position to each other and the earth, produce the complex tides which move saltwater landward to mix with freshwater inflow. Tidal mixing is augmented by seasonal winds and storms which greatly influence tide level and salinity.

The distribution and abundance of plants and animals is influenced by this dynamic physico-chemical gradient. The smallest organisms are transported by currents and tides. Larger organisms, capable of directed movement, seek out favorable physico-chemical conditions within the estuary. There is a pool of freshwater, estuarine and marine species of plants and animals which are common to the Gulf of Mexico. Yet when the relative abundance of these organisms is examined, each Gulf estuary appears to have a unique biota, which changes seasonally and from year to year (Monaco et al. 1989, Nelson 1992). The biota of each estuary is significantly different from the biota of adjacent estuaries to the east or west (Conner & Day 1987, Harper 1992). This apparently results from differences in the physico-chemical environment of each estuary. In making comparisons within or between estuaries it is important to consider the spatial and temporal variation of these environments. Organisms are responding to salinity and illumination gradients, sediment composition, and nutrient availability. Temporal gradients are established by episodic weather, diurnal patterns, tidal cycles, seasonal climate, solar cycles and geologic history. Thus circumstances are influenced by forces beyond the estuary, the watershed, the continent, or the planet. Any given environmental condition can be changed by waiting a few minutes or moving a few feet. Yet they are inextricably linked together.

The life of individual organisms may be measured in days or weeks for the smallest organisms to years for the largest. Populations persist beyond individual lifetimes, but may go extinct. Communities of different species may persist for lengthy periods but subtly change as component populations locally become extinct or invade, or numbers wax and wane. Ecosystems are difficult to define, have "fuzzy"

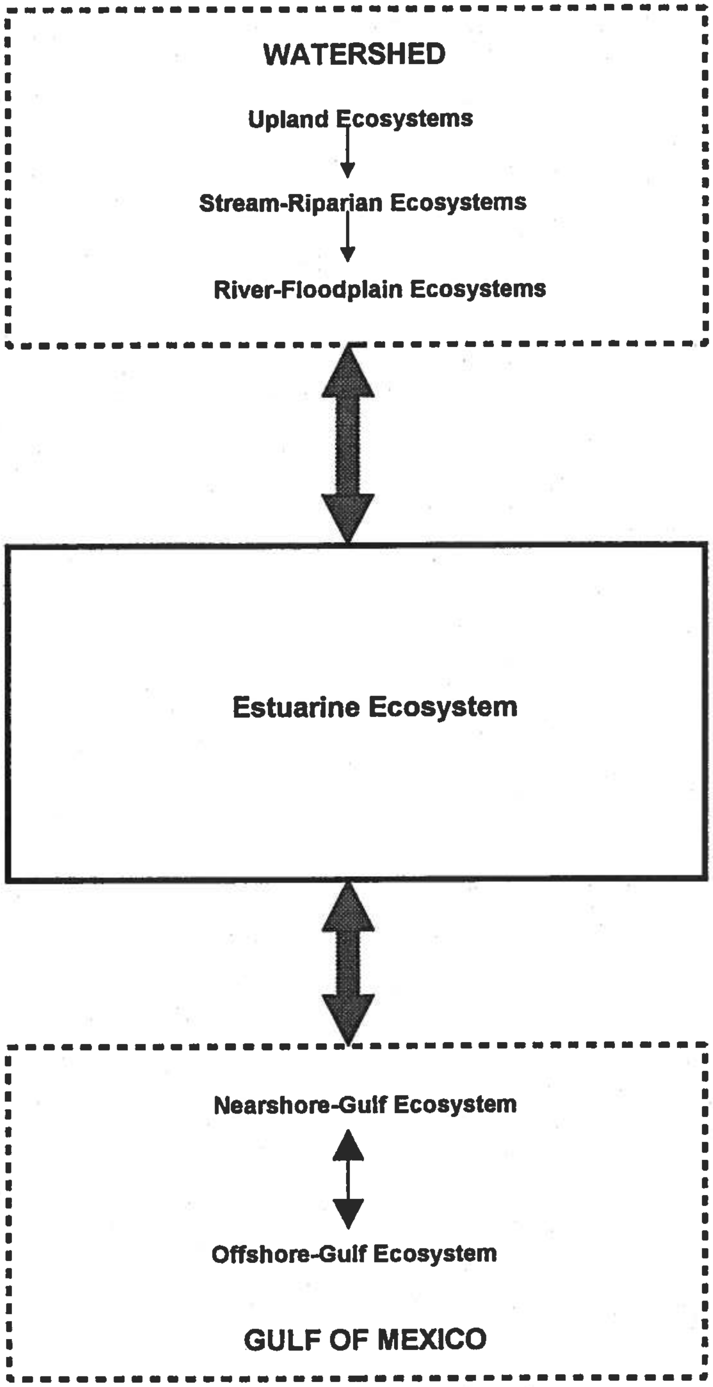

Figure 1. The Interrelationships of Coastal Ecosystems

edges, can be subdivided interminably, are notoriously "open" systems, and usually persist for lengthy periods (100s of years). Species have lengthy "lifespans" (100,000s or millions of years) that extend into geologic time (greater than estuary longevity) and broad ranges that encompass numerous ecosystems. From a simplistic viewpoint, a diverse species pool is available; whenever environmental conditions change, or an estuary is sufficiently perturbed, the pool of abundant, common, uncommon and rare species is reshuffled and a new ecosystem mix of species tolerant of the new conditions results. The estuarine environment has changed but the ecosystem persists with a different species mix of relative abundances; that is, rare species may become common, and vice versa.

Among the earth's ecosystems, estuaries may be the most closely connected to adjacent ecosystems of a different nature (Figure 1). The **upland ecosystems** of the watershed provide surface water and groundwater, sediments, nutrients, and organic matter. These create and are transported by the **stream-riparian ecosystems**, which coalesce to form the larger **river-floodplain ecosystems** that flow into estuaries. Many residents of the **estuary ecosystem** are transients from the **near-shore gulf ecosystem** which utilize the estuaries as critical nursery areas. Relatively few estuarine species, from plankton to fishes and birds, live out their entire life cycle within the estuary or are restricted to estuarine habitats (McFarlane 1993).

COMMON HABITATS OF GULF ESTUARINE ECOSYSTEMS

The Sabine Lake ecosystem is herein considered to include any part of the environment that is reached and covered by tidal waters with a salinity greater than 0.5 parts per thousand (ppt) on a regular basis. Tidal freshwaters (less than 0.5 ppt) are considered to be part of the river-floodplain ecosystem. Gulf estuaries typically can be subdivided into a number of specific habitat types, some always present while others may be absent. The ecological connections and trophic relationships of these habitats are very complex (McFarlane 1993). The largest and most conspicuous habitat is **open-bay water**. This habitat is 3-dimensional, and its lateral extent and vertical dimension are controlled by tides and winds. Open-bay water habitat is essentially featureless but it may exhibit gradients of salinity, illumination, temperature, dissolved oxygen, nutrients and turbidity. The primary producers, which capture solar energy and manufacture organic molecules, are various groups of phytoplankton. The primary consumers of these phytoplankton are four groups of zooplankton (nanno-, micro-, macro-, mega-), each larger than the preceding, and phytoplanktivorous fishes. The food chains can be quite lengthy, extending through zooplanktivorous fishes, piscivorous fishes, and terminating with piscivorous birds and marine mammals, and humans.

The second-largest habitat is the **open-bay bottom** (Armstrong 1987, Harper 1992, Harrel et al. 1976). This lies beneath the open-bay waters but, for all practicable purposes, it can be considered a 2-dimensional habitat. Living organisms are restricted to a zone a few inches deep. Except for shallow areas where light can reach the bottom, photosynthesis is quite restricted and limited to benthic algae. The food web is based on detritus, dead organic material that descends from open-bay waters above or is transported onto the habitat by currents. Fungi and bacteria play a key role in the decomposition of organic material which reaches the bottom. A community of microfauna eat these fungi and bacteria and, in turn, are consumed by a community of larger meiofauna within the sediments. Larger organisms live on the surface of the bottom (epifauna) or buried in the surface sediment (infauna) and are, in turn, consumed by larger predators from the open-bay water habitat. Bottom organisms play a vital role in recycling nutrients to the open waters.

Patches of different habitat can be found within the open-bay bottom matrix. The most common is **oyster reef** habitat (Bahr & Lanier 1981, Cake 1983, Zimmerman et al. 1989). Oysters can exist wherever a hard substrate, sufficient current, and suitable salinity can be found. Once established, oyster shells create new habitat for additional oysters. Currents are necessary to transport food to the reef and carry away sediment, feces, and pseudofeces. The oyster reefs are shallowly 3-dimensional in that the irregular oyster shells cemented together create numerous tiny niches that are occupied by dozens of other small species. Suspension feeders, deposit feeders, crustal algae, grazers, and predators create a complex food web. Oyster reefs may occur in the intertidal zone where they are exposed to air for a part of the tidal cycle. Elsewhere, patches of **submergent aquatic vegetation** form grass meadows inhabited by a diverse community of grazers, suspension feeders and deposit feeders. Submergent grasses are eaten directly, provide substrate for the attachment of algae which also are grazed, and die at the end of the growing season, providing detritus to the surrounding open-bay bottom detritivore community. There is little information regarding the presence or absence of grass habitat in Sabine Lake.

A habitat of major importance is the **peripheral emergent marsh** (Weigert & Freeman 1990, Stout 1984, Odum et al. 1984). The erect stems of these plants lift their photosynthesizing leaves and stems above the water so they are not limited by light availability, as are the submerged aquatic grasses. These marshes are among the most productive plant communities in the world. They are uniquely subjected to predictable, periodic subsidies of tidal energy that import nutrients and export waste products with each tidal cycle. Emergent marshes are categorized as salt, brackish, intermediate or freshwater by the plant species characteristic of each. The number of plant species, and competition between the species, increases along the saltwater-to-freshwater gradient. Direct grazing of these emergent plants is somewhat limited. Their major contribution to the estuary is the organic detritus that results from their decomposing leaves after death. In some instances unvegetated **intertidal mud flats** occur on the periphery of the estuary (Peterson & Peterson 1979). These algae-based benthic communities are important foraging areas for fishes when inundated and for birds when exposed. They serve as a nutrient sink, and their sediments can give up adsorbed nutrients to establish chemical equilibrium as chemical concentrations in the water column decline. The extent of intertidal mud flats at Sabine Lake is undetermined.

The major trophic components of these habitats are depicted in Figure 2. The primary producers are phytoplankton in the open-bay water habitat, and macrophytes and attached algae in the emergent marsh. The open-bay bottom and oyster reef lack significant primary producers and the food web pyramids are composed primarily of consumers dependent on food produced in other habitats, such as the overlying waters and adjacent marshes.

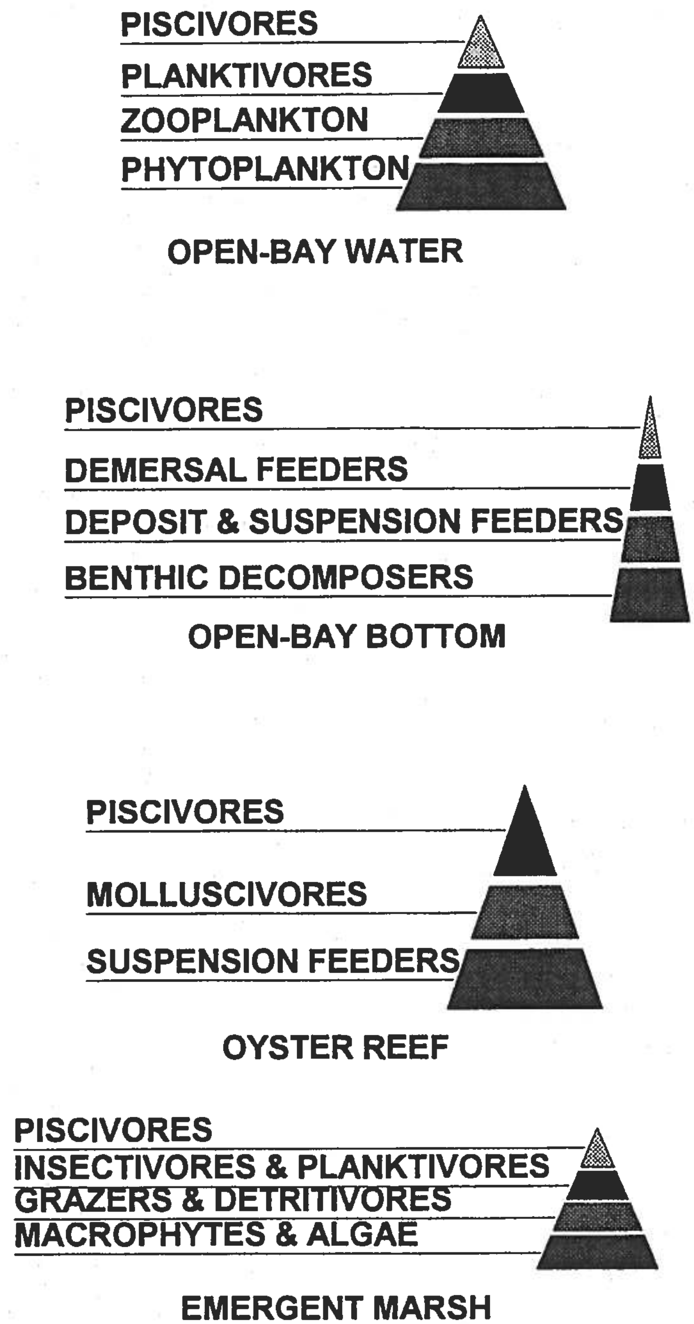

Figure 2. Major Trophic Components of Estuary Habitats

ECOSYSTEM CONNECTIONS AND CONSTRAINTS

There is considerable exchange of chemicals and organisms between Sabine Lake and the adjacent ecosystems and between the various habitats within the lake (Figure 3). As with all resources, the supply can be too little, just right, or too much, and be a limiting factor, or support productivity, or actually constrain productivity. Freshwater is the key ingredient; it provides the salinity gradient that permits organisms to seek out favorable or optimum conditions for growth, and it physically transports the other key ingredients (Livingston 1992). With too little freshwater inflow, salinity within the lake rises and inadequate supplies of the other key resources, particularly floodplain detritus and nutrients, are delivered to the lake. With too much freshwater inflow, salinity drops, sediments can cover reefs and grass meadows, and nutrients are rapidly transported through the lake directly to the nearshore gulf ecosystem. These interacting ecosystems function best when the lake acts as a sediment and nutrient trap, and the turbid waters slosh back and forth within the estuary with each tide.

If too little sediment is transported into the system, the balance between erosion and accretion within the delta can shift, leading to a loss of wetlands. Estuaries are sediment sinks.

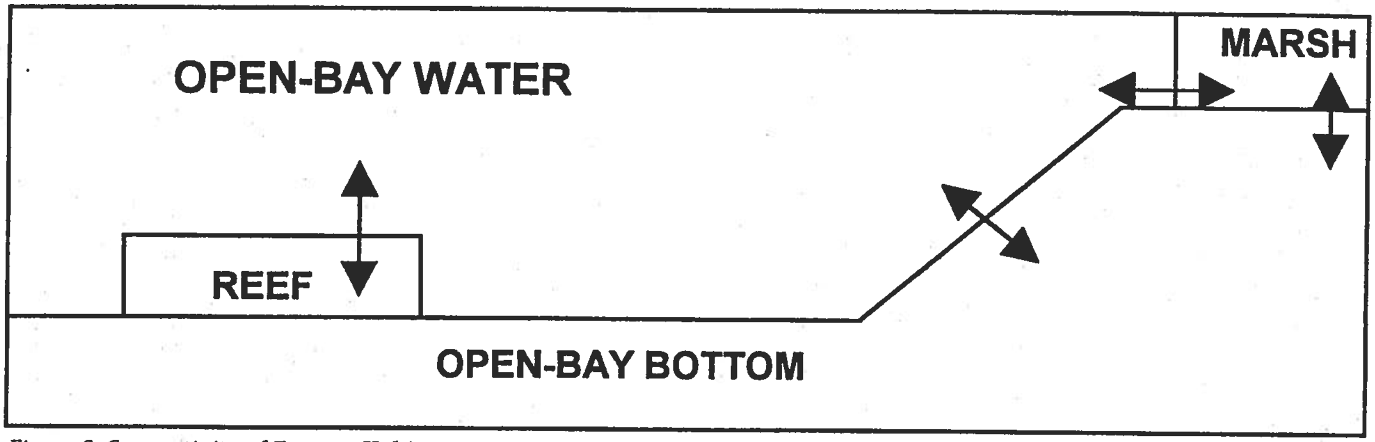

Figure 3. Connectivity of Estuary Habitats

Too much sediment shortens the life span of an estuary because it simply fills up. Fine sediments play a vital role in mineral cycling between the open-bay water and open-bay bottom habitats. Excessive sediment increases turbidity within the water column and constrains photosynthesis by phytoplankton, benthic algae and submergent grasses.

If too few nutrients are tranported into the system, primary productivity of phytoplankton is constrained and the entire food webs of the pelagic, benthic and reef communities are affected. If nutrients become excessive, certain algae may gain prominence and "bloom", inhibiting other phytoplankton species, reducing water clarity and the photosynthetic activity of benthic algae and submergent grasses. Some blooms produce chemicals that are toxic to other forms of life. As excessive numbers of the bloom species die and sink to the bottom, oxygen can be depleted by the stimulated activity of benthic decomposer organisms.

ECOLOGICAL IMPACTS OF HUMAN ACTIVITIES

Humans are forever modifying the natural environment to facilitate navigation, transportation, economic activities, supplies of natural resources and other beneficial uses. History has repeatedly established that it is impossible to do merely one thing; every action taken seems to have at least one undesirable consequence, often many (Hardin 1985). Just as freshwater and saltwater have been shown to be the key integrator of the estuarine environment, water resources have been the major attraction to human intervenors. Impoundments have been created, navigation channels have been dug, and levees have been raised to facilitate a multitude of beneficial uses without regard for the associated detrimental environmental consequences. It must be remembered that prior to navigation "improvements", Sabine Lake was virtually a freshwater ecosystem and provided water for rice irrigation in the late 19th century, when shallow sand bars at the river mouth obstructed deep saltwater intrusion (Ward 1983).

Dams constructed on the Sabine and Neches rivers have resulted in large reservoirs, neither river nor lake, that strip sediments and nutrients from the flowing waters (Soballe et al. 1992). Small floods may be absorbed completely. Large floods have their peak flow attenuated and their duration extended. The temperature of discharged water may be lower than normal river temperatures. The seasonal flow of water may be altered; for example, demand for hydroelectric power from Toledo Bend is greatest during the summer air-conditioning peak usage, resulting in substantial river flow during the summer when natural flow and salinity would be lowest. This resulted in the collapse of the Sabine Lake white shrimp fishery (Sheridan et al. 1989).

Barge canals, such as the Gulf Intracoastal Waterway (GIWW), and their associated dredged material disposal areas, disrupt surface water flow, divert water to other water bodies, bisect small coastal streams with deep tranverse channels, and alter the hydrology of adacent wetlands. The GIWW diverts substantial Port Arthur ship channel flow westward to East Bay of the Galveston Bay system and may increase pollutant levels in that water body (Summers & Hornig 1993). Ship channels, due to their great depth compared to natural river channels, facilitate upstream density currents and saltwater intrusion (Ward 1983). Sabine Lake is unique in that, at times, salinity is greater at the upper end of the lake than farther seaward, due to the Port Arthur ship channel and Sabine-Neches canal. Saltwater barriers have been constructed on the Neches River. Groins and jetties modify shoreline sediment transport.

Levees and wetland impoundments modify the hydrologic regime of wetlands to favor certain plants and animals but restrict the flow of nutrients and detritus to the estuary, and limit access to the wetlands by estuarine organisms. The discharge of point and nonpoint source pollutants degrades water quality throughout the estuary. Health advisories warning against fish and shellfish consumption, and closure of shellfish beds to harvesting result from river and estuary redistribution of these pollutants. Figure 4 summarizes the primary and secondary impacts which may result from human modifications to the hydrologic regime of this estuary (Gosselink et al. 1979). Some species have already dwindled to near extinction (Pitman 1991). Benthic communities are known to have been impacted (Hendricks et al. 1969, 1974; Harrel et al. 1976). Interbasin water transfer also has the potential to transfer organisms and create additional problems (Geo-Marine Inc. 1996).

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Figure 4.
Primary and Secondary Effects of Hydrologic Regime Modifications

- HYDROLOGIC REGIME
  - Upstream Inflow
  - Basin Circulation
  - Nearshore Gulf Circulation
- MODIFICATION
  - Dams and Levees
  - Canals and Spoil Banks
  - Navigation Channels
  - Groins, Jetties and Bulkheads
  - Control Structures
  - Land Use
- PRIMARY EFFECTS
  - Freshwater Supply
  - Salinity
  - Sediment Input
  - Sediment Deposition/Erosion
  - Water Levels
  - Overland Flow
  - Circulation
- SECONDARY EFFECTS ON BIOTA
  - Migrations—Routes and Timing
  - Salinity Tolerance
  - Food Availability
  - Substrate Suitability
  - Production
  - Access
- SECONDARY EFFECTS ON HABITAT FUNCTION
  - Community Structure
  - Productivity
  - Community Distribution
  - Flux of Organic Materials
  - Flux of Inorganic Nutrients
- SECONDARY EFFECTS ON HABITAT TYPE AND AREA
  - Deposition/Erosion/Subsidence
  - Salinity Shifts
  - Impoundments
  - Spoil Areas
  - Drained Areas
  - Habitat Interaction-Interface Effects
  - Eutrophication

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GEOLOGICAL AND HISTORICAL DEVELOPMENT OF SABINE LAKE—AN OVERVIEW

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Reconstruction of the late Pleistocene geologic history of the southeastern Texas coast illustrates how climate and sea-level fluctuations influenced the location and morphology of Sabine Lake and the composition of sediments filling the Lake. Sabine Lake is an estuary and unfilled former river valley that was constructed during the last glacial period (Kane, 1955). As continental glaciers in North America expanded and sea level began falling about 100,000 years ago, the Sabine and Neches Rivers began excavating a valley in response to lowered base level. Maximum incision of the valley to a depth of about 120 ft below Sabine Lake (Kane, 1955) occurred about 20,000 years ago when sea level was atits lowest position, or about 300 ft below present sea level. As the ice masses melted about 18,000 years ago, sea level began rising rapidly and the incised valley beneath Sabine Lake was flooded about 9,000 years ago when sea level was at about -70 ft (Nelson and Bray, 1970; Anderson et al., 1991; Morton et al., 1995). Initially fresh water marsh formed on the abandoned floodplain of the Deweyville river deposits. Small bayhead deltas also formed where the Sabine and Neches Rivers entered the drowned valley. Later, as sea level rose irregularly and with minor reversals toward its present position, the valley was inundated by more saline water and began filling with estuarine and marine sediments characterized by oysters and brackish water clams. About 3,500 years ago, when sea level reached its present position, Sabine Lake was separated from the Gulf of Mexico by advancement of the Gulf shoreline and deposition of the beach ridge/mudflat complex that is known as the chenier plain (Gould and McFarlan, 1955). High volume fresh-water inflow into Sabine Lake helped maintain Sabine Pass as a narrow link between the water bodies.

Depositional remnants of the late Pleistocene Sabine and Neches Rivers are collectively referred to as "Deweyville" on the basis of elevated terraces and associated fills that are preserved along the valley walls. These terrace features were first recognized in the Sabine valley at the town of Deweyville by Bernard (1950). The late Pleistocene rivers were characterized by moderately large bed-load streams with relatively uniform discharge that migrated laterally and filled the incised valley with sandy point-bar deposits. Because muddy overbank sediments are noticeably absent in these late Pleistocene river deposits, they are mined extensively for sand and gravel aggregate. Along the valley margins and at the base of the valley, three Deweyville terraces are preserved like stair steps that are progressively lower and located toward the valley axis. The youngest (lowest) terrace controls gradients, channel patterns, positions, and surficial drainage of the modern Sabine and Neches Rivers. The modern rivers are narrow, sinuous, flashy-discharge streams that transport a muddy organic-rich suspended load. The muddy overbank deposits of these rivers help maintain fixed channels that change position by meander-bend cutoff and avulsion during deep floods. The lack of abundant abandoned courses and oxbows within the modern floodplain indicate that the modern rivers have not substantially reworked the Deweyville deposits.

The differences in channel pattern, sediment composition, and depositional style between the late Pleistocene and Holocene rivers suggest fundamentally different physical processes. River discharge during the late Pleistocene must have been largely contained within the channel banks, whereas overbank flooding and vertical aggradation of the floodplain during the Holocene and modern was frequent. Greater and more uniform annual river discharge during the late Pleistocene can be attributed to a cooler and wetter climate that produced precipitation throughout the year and thick soils in the drainage basins. Cooler temperatures and restricted size of the Gulf of Mexico when sea level was lower also would have hindered or prevented the formation of tropical cyclones. Thus annual distribution of precipitation would have been relatively uniform, and the thick upland soils would have minimized surface runoff and contributed to more uniform river discharge. Post-glacial changes in upland vegetation, stripping of upland soils, and generation of tropical cyclones produced flashy peak river discharge, frequent overbank flooding, and loads of suspended sediment (mud) that characterize the Holocene rivers.

Extant discharges of the Sabine and Neches Rivers are largely moderated by flood control structures and freshwater impoundments upstream of Sabine Lake. The volume of sediment presently reaching the Sabine/Neches floodplains and associated coastal marshes in Sabine Lake and the volume of sediment needed to sustain wetlands in these areas is unknown and represents one of the major gaps in scientific data for the river/estuarine system. Artificial reductions in peak discharge of the rivers may have reduced the volume of sediment deposited on the floodplains, in the delta regions, and in Sabine Lake, which would contribute to the historical loss of wetlands observed.

Morphological changes in the rivers during historical time have been related primarily to human activities. The lower reaches of the rivers initially were cleared of log rafts and snags, realigned, and deepened to improve navigation by steamboats (U.S. Army Corps of Engineers, 1880). Subsequent dredging of the river channels and deposition of dredged material on the river banks was conducted to permit navigation by deep draft vessels. Alterations to the river floodplains included removal of dense stands of large cypress trees that were logged for lumber and construction of high mounds of dredged material along the natural levees. These high mounds alter the floodplain hydrology and may prevent some overbank sediment from being deposited on the floodplain.

Marshes composing the Louisiana side of Sabine Lake have remained essentially natural whereas the Texas side of the Lake has been greatly altered by the dredging of the Sabine-Neches channel to Port Arthur, Beaumont, and Orange. Sediment dredged from the western margin of the Lake to form the waterway was placed in disposal areas to protect the channel from waves and to reduce maintenance dredging that is periodically required to remove shoals. Some of the dredged material was used to create made land at Port Arthur that is used for wharves and other docking facilities. Most of the western (Texas) shore of Sabine Lake has been artificially hardened and consists of rock revetments constructed to contain the dredged material and protect it from erosion. Before it was artificially stabilized, the western shore of Sabine Lake was being eroded by waves generated by the predominant southeastern winds. This erosion made the Lake wider than its original valley width. Unprotected delta plain, coastal marsh, and chenier plain shores of southwestern Louisiana continue to retreat as a result of frequent storm waves and inadequate sediment supply.

Water depths in Sabine Lake generally range from 3 to 8 ft. Greatest depths occupy the eastern two-thirds of the open lake, which generally coincides with the axis of the drowned valley. The shallower platform that occupies the western third of the open lake was formed by wave erosion. Natural shoals are also located near the mouths of the rivers and along the channel flanking the chenier plain that connects Sabine Lake with Sabine Pass.

Dredging of Sabine Pass began in 1875 when the natural water depth over the outer bar was about 7 ft (U.S. Army Corps of Engineers, 1877). Projects designed to deepen the entrance to Sabine Lake, construct a stable navigation channel, and reduce channel shoaling by construction of jetties were intermittent throughout the late 1800s and early 1900s. The channel was progressively deepened and the jetties lengthened and currently the jetties extend nearly four miles into the Gulf of Mexico; the authorized project depth of the entrance channel is 42 ft.

Sabine Lake forms a trap for sediments transported by the Sabine and Neches Rivers, therefore the floor of the Lake is composed primarily of mud, sandy mud, and muddy sand (White, et al., 1987). Mixtures of mud, sand, and shell occur in the southern part of the Lake in the vicinity of oyster reefs, along mounds of reworked dredged material, and where the beach ridges in southwestern Louisiana are being eroded. High concentrations of sand are restricted to areas surrounding the mouths of the Sabine and Neches Rivers. Bottom sediment textures are slightly coarser on the Texas side of the Lake. This asymmetrical pattern generally reflects the regional coastal processes as well as the relationship between grain size and water depth. The finest sediments (muds) tend to be concentrated in the deepest parts of the Lake, whereas slightly coarser sediments are deposited along the western margin in shallow water where the fetch is greatest and highest waves impinge on the shore. Concentrations of metals (iron, lead, copper, zinc, chromium) in the surface sediments display patterns that are similar to the distribution of sediment textures (White, et al., 1987). Highest concentrations of metals generally are associated with the muddy sediments whereas concentrations of metals tend to be lower where sediments are coarser. Some high concentrations of metals in the sediments were taken from the ship channel, which suggests an anthropogenic contribution related to industrial or municipal waste water discharged along the channel.

The physical processes that continue to influence Sabine Lake and the lower reaches of the Sabine and Neches Rivers are reduced peak river discharge and sediment influx, frequent intense winter storms and tropical cyclones, and a relative rise in sea level. The relative rise in sea level in the Sabine Lake region is caused primarily by land surface subsidence (Swanson and Thurlow, 1973). Some of the subsidence is related to natural (geological) compaction of sediments in the basin and some is locally caused by extraction of subsurface fluids, principally oil, gas, and associated formation water. Man-induced subsidence near oil and gas fields may occur across the entire area of production or it may be concentrated along faults activated by the fluid withdrawal. Although the tide gauge record at Sabine Pass is incomplete, the historical trend of sea level is similar to that recorded at Galveston where the rate of relative sea-level rise is about 2.6 ft every hundred years (Lyles et al., 1988).

The sediments beneath Sabine Lake record a rich history of climatic changes and sea-level fluctuations that altered the natural ecosystems and required environmental adjustments to rapidly changing conditions over thousands of years. Some of the older historical ecological changes may be preserved at the surface in shell middens at archeological sites along the waterways. Detailed examination of shell midden strata may reveal how the estuarine organisms responded to changing salinity, water depth, and sediment type caused by regional variations in rainfall and sea level position.

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GENERAL DESCRIPTION OF TEXAS AGENCIES WITH RESPONSIBILITY FOR SABINE LAKE

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Responsibility for the planning, management and regulation of the surface water resources within the State of Texas falls under the purview of several federal and state agencies. While the U.S. Environmental Protection Agency is charged the implementation and enforcement of the Federal Clean Water Act , as amended, this discussion will focus on the State agencies which have a primary role in the protection/ management of Sabine Lake and major tributaries to that system.

Activities which have the potential for affecting the resources associated with Sabine Lake include, but are not limited to: energy related activities, development, transportation, agricultural, recreational, waste management, impoundments and diversions, emissions of air pollution, oil spills, and nonpoint sources of pollution. Just as there are a multitude of activities which could affect coastal resources, there are several state agencies which have jurisdiction over these activities, at times overlapping. In an effort to minimize redundancy and to coordinate the authorities granted to the various state agencies, the State of Texas has developed a coastal management program and is seeking federal approval under the Coastal Zone Management Act. The program is based on existing state laws and agency regulations and seeks to bring a coordinated approach to the management of coastal resources.

Construction of electric generating facilities, transmission lines and activities associated with oil and gas exploration and production fall within the purview of the Public Utility Commission (electric), and the General Land Office (GLO) and Railroad Commission (RRC) (oil and gas). The GLO also has chief responsibility for addressing prevention of, response to, and remediation of coastal oil spills.

Development and related activities associated with residential, commercial, and industrial construction may be regulated by the Texas Parks and Wildlife Department (TPWD), Texas Natural Resource Conservation Commission (TNRCC), or the GLO. Often times, these activities require the issuance of permits such as the TPWD's sand, gravel and marl permit.

Transportation construction projects and maintenance programs such as the dredging of the intra-coastal waterway, are managed by the Texas Department of Transportation (TxDOT). In addition, the GLO, TNRCC, and TPWD have specific authority with regard to dredging activities and the disposal of dredged material.

Agricultural activities related to farming, ranching, and aquaculture are managed/regulated by the Texas State Soil and Water Conservation Board (TSSWCB). Primary responsibility for water quality management for these activities (non-point source runoff) also falls within the jurisdiction of the TSSWCB.

The remaining major activities that could have an impact on the Sabine Lake system include waste management, impoundments/diversions and air emissions. While there are certain actions that may take place with each of these activities which would result in multi-jurisdictional situations, the primary management authority lies with the TNRCC.

This presentation does not capture the role of federal agencies and their jurisdiction over the afore-mentioned activities. Nor, does it attempt to identify the authority of the State of Louisiana relative to the Sabine Lake System. To that extent, the States of Texas and Louisiana created the Sabine River Compact in 1953, to oversee the management and apportionment of "waters of the Sabine Basin". Any use of water subject to the Compact, by either State, will require approval by the governing board of the Compact.

Water Exchange Patterns and Salinity of Marshes Between Calcasieu and Sabine Lakes

Ronny Paille
U.S. Fish and Wildlife Service

The Sabine National Wildlife Refuge is located between Calcasieu and Sabine Lake, midway between the Gulf Intracoastal Waterway (GIWW) to the north and the Gulf of Mexico to the south. Salinity of refuge and adjacent marshes has been monitored routinely by refuge personnel since 1966. Water flow patterns were monitored via routine visual observations during 1991 and 1992. Major waterways within the area and primary salinity sampling stations are shown in Figures 1 and 2 respectively.

WATER FLOW PATTERNS

Except for the three freshmarsh impoundments on Sabine National Wildlife Refuge, and several privately-owned freshmarsh impoundments in the northeast portion the project-area, the remaining marsh south of the GIWW is tidally-influenced. Water level and the direction of water flow may vary daily depending upon tide, wind, precipitation, river stage, barometric pressure, and water control structure operations. Wind is often the primary force determining water flow patterns near large water bodies resulting in flow patterns that overpower the effects of lunar tides. Described below are the most predominant wind-induced water flow patterns.

Strong prolonged southeast, and south winds push large volumes of Gulf water into Calcasieu and Sabine Lakes causing a rise in lake water levels. Such conditions often occur prior to a frontal passage and result in continuous or near-continuous incoming tides at water exchange points bordering Calcasieu and Sabine Lakes. The resulting high water levels in those lakes cause strong incoming tides to occur in the surrounding marshes. Low barometric pressure also produces high Gulf and lake waters, and may result in similar strong incoming tides.

The large expanse of deteriorated marsh and shallow open water extending northward from Backridge Canal (on Sabine Refuge) to Hackberry is also subject to wind effects. Prior to a frontal passage, strong prolonged southeast and south winds push water northward. Consequently, water levels at the southern end of the open water area are lowered while water levels at the northern end are elevated. The low water level condition produced at the southern end of the open water area facilitates flow into that area from relatively saline sources such as Calcasieu Lake via Hog Island Gully, and Kayo Bayou. Because the water level of Calcasieu Lake is typically high under such conditions, a large head differential is created, importing large volumes of water, depending on operation of refuge water control structures along Louisiana Highway 27. Additionally, Roadside Canal (from the West Cove Canal water control structure to North Line Canal) also flows strongly toward the southern end of the open water area. The Roadside Canal flow also serves to import Calcasieu Lake water via the Headquarters Canal water control structure and the West Cove Canal water control structure. During such winds, Backridge Canal also flows northward toward the southern end of the open water area.

At the northern end of the open water area, wind-induced high tides cause water to be discharged through Rycade Canal toward Black Lake. Because those winds also lower water levels in the southern end of Black Lake, a substantial head differential may be created, and the flow through Rycade Canal is often very strong. That flow is now managed by a structure installed by the Louisiana Department of Coastal Restoration. Typically, waters draining from the wind-induced high tide area (sawgrass die-out area) are extremely turbid due to resuspended and eroded organic material. North Line Canal also serves to discharge large volumes of water from the wind-induced high tide area toward Sabine Lake, via Black Bayou.

Strong prolonged northwest, north, and northeast winds lower water levels in the nearshore Gulf of Mexico and depress water levels within Calcasieu and Sabine Lakes. Such conditions occur after frontal passages and often result in continuous

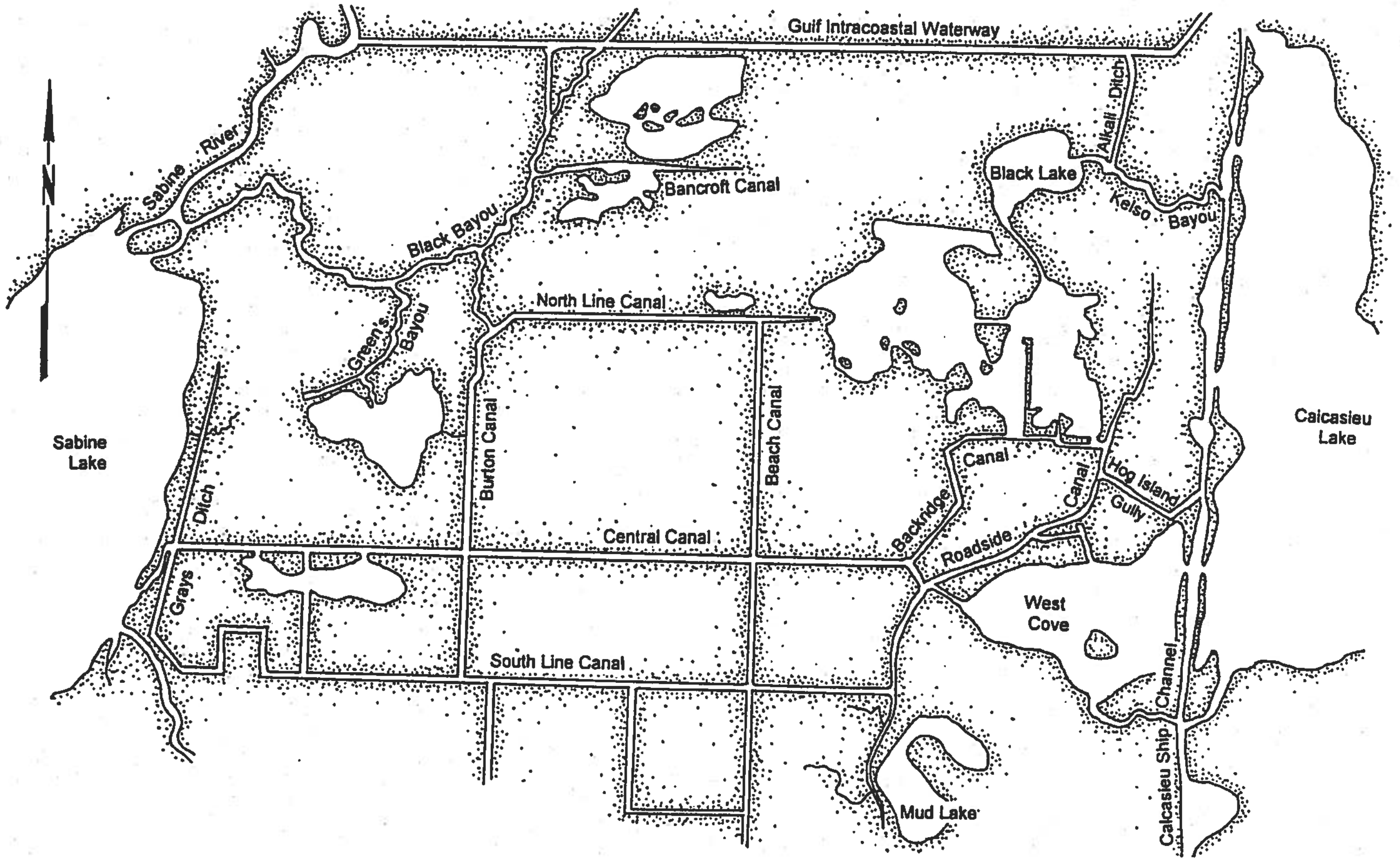


Figure 1. Schematic map showing the locations and names of major canals and waterways.

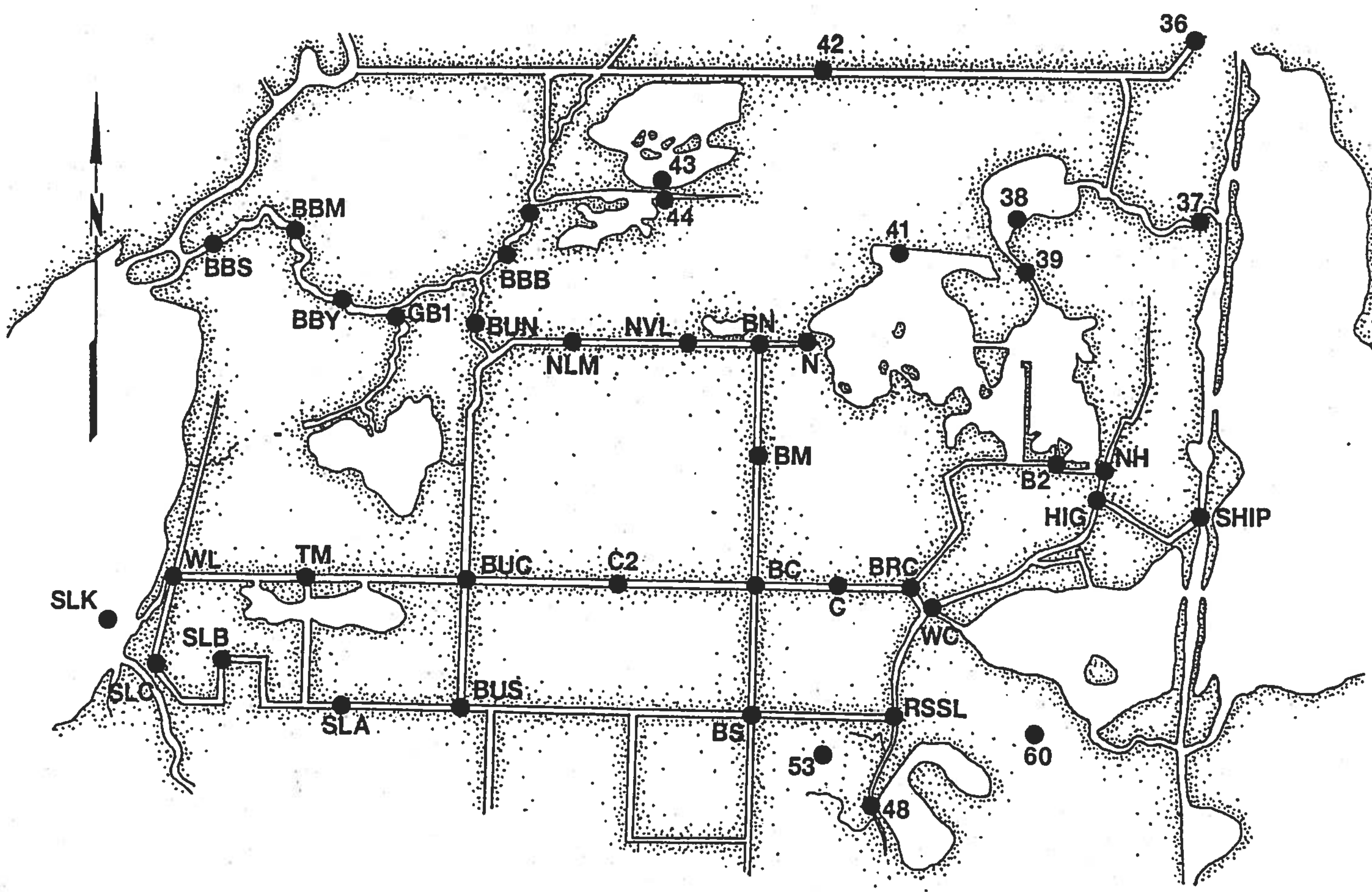


Figure 2. Schematic map showing the locations of certain salinity monitoring stations.

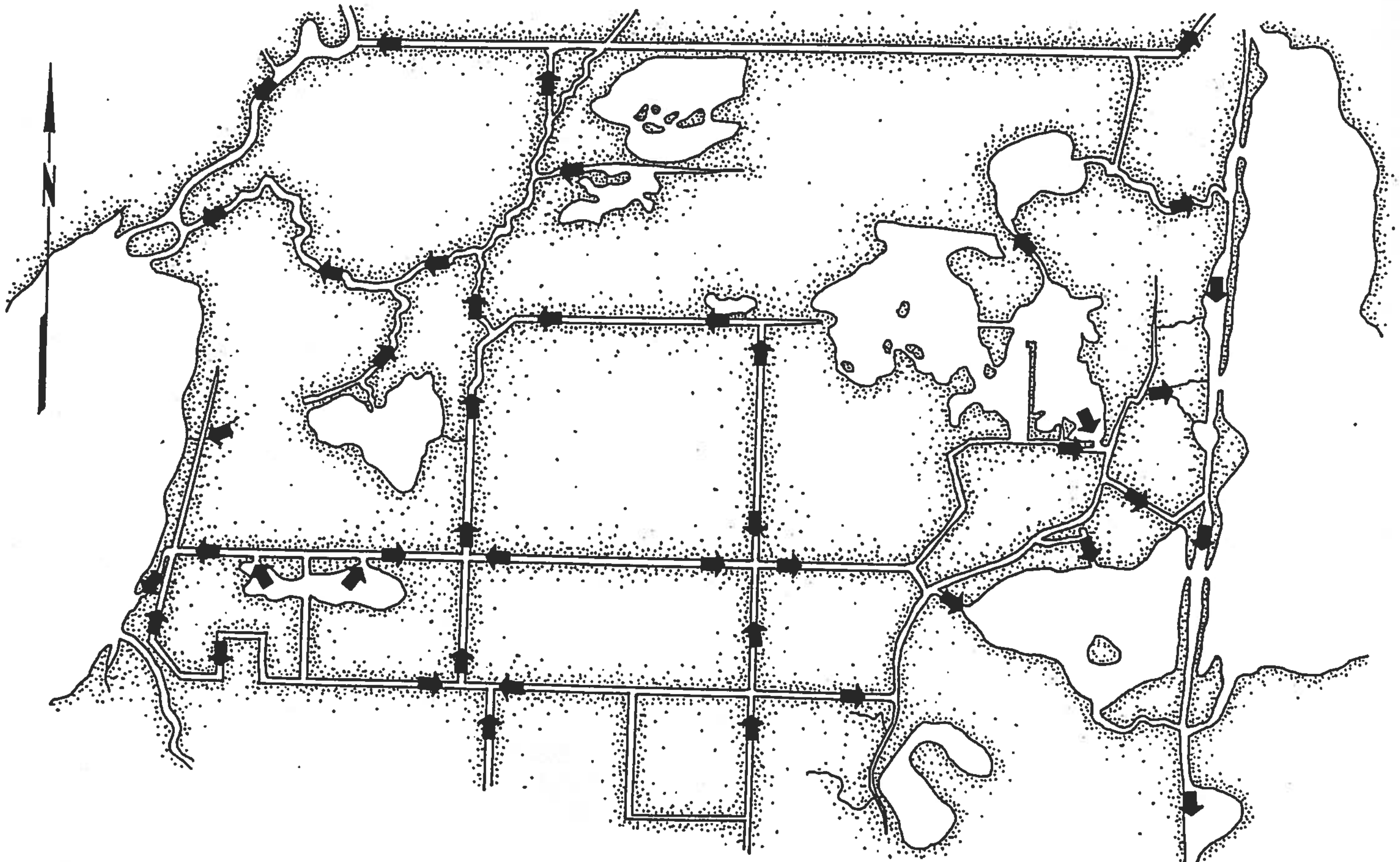


Figure 3. Schematic map showing the direction of water flows during outgoing tide.

tidal outflow at water exchange points bordering Calcasieu Lake and Sabine Lake.

The large expanse of deteriorated marsh and shallow open water which extends from Backridge Canal to Hackberry is also affected by strong northwest and north winds following a frontal passage. Under those conditions, water levels are elevated at the southern end of the open water area. Because water levels in Calcasieu Lake are also lowered, strong flows toward Calcasieu Lake are produced. Backridge Canal and Roadside Canal also serve to discharge large volumes of water from the wind-induced high tide area toward Calcasieu Lake via the Headquarters Canal and West Cove Canal water control structures. Typically, waters draining from the wind-induced high tide area (sawgrass die-out area) are extremely turbid due to resuspended and eroded organic material. At the northern end of the open water area, water flow patterns in Rycade Canal may vary. Following a frontal passage, that portion of North Line Canal west of Beach Canal usually drains toward the west.

Lunar tides often determine flow patterns during the summer months when winds are typically light and variable. Normal flow patterns during outgoing tides are generally similar to outflows associated with frontal passages. Additionally, normal flow patterns associated with incoming tides are generally similar to that during inflows associated with strong southerly winds preceding a frontal passage. Flow velocities associated with lunar tides are often less than velocities associated with tides induced by strong winds.

The GIWW, South Line Canal, Central Canal, and North Line Canal provide hydrologic connections between Sabine Lake and Calcasieu Lake. During ebb tide, those canals drain project-area marshes simultaneously into both Sabine and Calcasieu Lakes. This creates zones of little or no flow in some sections of canal. East of the zone, water flows east toward Calcasieu lake. West of the zone, water flows west toward Sabine Lake. In other cases, canals allow project-area marshes to drain into Sabine Lake via the Willow Bayou and the Black Bayou watersheds. The location of the no flow zones varies depending upon wind, water levels, river stages (Calcasieu and Sabine Rivers), and the degree to which refuge water control structures are open. According to observation made by refuge personnel during 1991 and 1992, water flows and divergent flow zones are illustrated in Figure 3.

Where those no flow zones are located near areas of extensive marsh breakup, eroded organic material tends to settle out in the canal shoaling the canal to the extent that emergent vegetation may fill in as it has in Central Canal west of station BUC. Similarly, portions of Beach Canal and Backridge Canals have been shoaled such that only airboats can pass.

SALINITY

When refuge personnel began collecting salinity data in 1966, approximately 15 stations were monitored once a month. In 1984, the number of salinity sampling stations was increased to approximately 27. In 1990, the sampling frequency was increased to once every two weeks. From the latter part of 1990 through early 1992, a number of addi-

Table 1: Average Annual Salinities — Sabine NWR

Year	BC	BN	BS	BUC	BUN	GB1	NH	SHIP	Mean
1966	2.4	3.0	2.3	2.6	2.8	—	8.3	11.7	4.7
1967	8.5	7.7	4.9	6.7	7.4	7.5	13.7	17.4	9.2
1968	3.6	4.3	3.1	2.6	2.9	4.0	9.9	17.9	6.0
1969	3.6	3.7	3.7	3.3	3.3	4.1	9.9	11.1	5.3
1970	6.2	7.3	3.8	3.8	4.5	4.9	14.1	17.1	7.7
1971	6.6	7.9	3.5	5.8	6.3	7.4	14.4	17.3	8.7
1972	4.7	6.2	3.0	3.6	4.1	5.3	12.0	15.4	6.8
1973	2.5	1.7	1.3	1.4	1.1	1.3	6.0	6.1	2.7
1974	3.6	3.7	3.8	2.4	2.3	2.4	8.7	8.9	4.5
1975	3.7	2.4	3.3	1.8	1.5	2.0	5.5	3.8	3.4
1976	7.6	4.9	6.4	2.6	2.7	3.2	13.5	8.7	6.2
1977	3.8	5.0	3.8	2.4	2.7	3.4	00.0	11.9	5.4
1978	8.7	10.9	6.1	4.8	5.3	6.3	14.1	13.1	8.7
1979	1.9	2.2	1.3	1.4	1.1	1.7	6.3	4.7	2.6
1980	6.4	3.7	4.5	2.9	2.6	4.2	10.0	8.6	5.4
1981	8.2	9.5	7.3	6.1	6.0	7.9	18.4	16.8	10.0
1982	6.0	9.7	3.5	6.6	7.7	6.8	10.9	12.2	8.2
1983	—	—	—	—	—	—	—	—	—
1984	7.3	6.9	8.4	5.0	5.0	5.4	15.5	16.8	8.8
1985	7.1	6.6	6.3	4.5	4.9	6.1	14.9	15.4	8.2
1986	6.9	6.8	8.8	4.6	4.7	5.3	18.5	17.3	9.2
1987	4.4	3.6	4.6	4.3	4.1	4.7	13.5	15.7	6.9
1988	4.8	4.0	3.8	3.9	4.5	6.2	16.6	18.8	7.8
1989	5.7	2.7	5.6	2.3	2.3	3.1	9.9	17.0	6.1
1990	3.8	3.0	4.8	2.9	2.9	3.8	11.5	12.0	5.6
1991	1.7	1.1	1.8	1.0	1.0	1.7	6.5	9.4	3.0
1992	3.0	1.8	2.6	1.9	1.8	2.7	8.8	4.4	3.4
1993	2.5	2.3	2.7	1.4	1.5	2.6	10.3	—	3.3
Mean	5.0	4.9	4.3	3.4	3.6	4.4	11.6	12.8	6.2

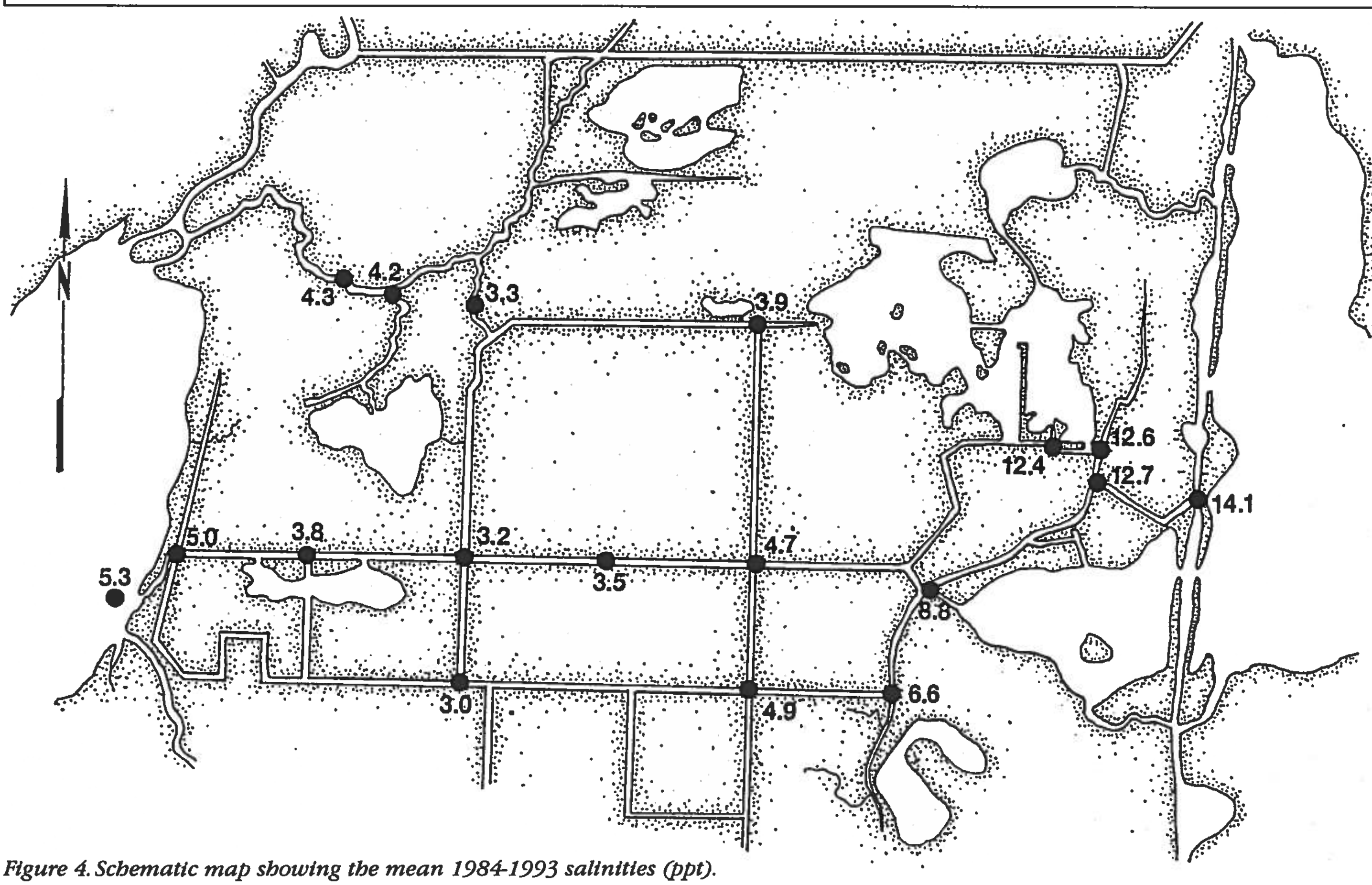


Figure 4. Schematic map showing the mean 1984-1993 salinities (ppt).

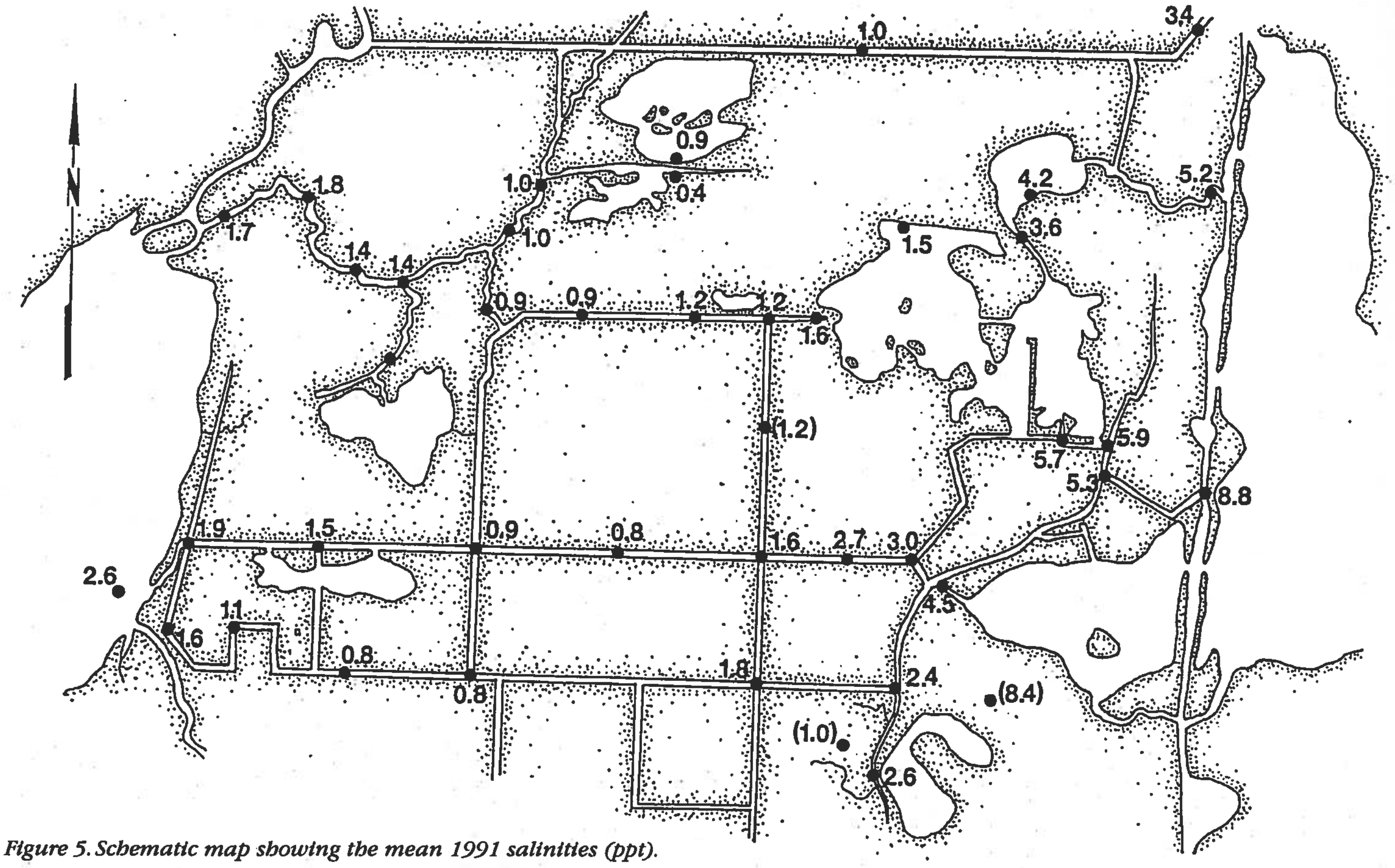


Figure 5. Schematic map showing the mean 1991 salinities (ppt).

tional off-refuge stations were sampled. Throughout the 1960s, and 1970s, salinities were determined via titration. In the 1980s to present, Beckman conductivity/salinity meters were used to measure salinity in situ.

Average annual salinities from stations sampled from 1966 through 1993 are compiled in Table 1. That table shows that salinities in the Sabine Estuary are lower than that of the Calcasieu Estuary. The table also shows the extent to which annual salinities have fluctuated. Examination of the mean annual salinities (right column) indicates that area salinities were consistently high throughout most of the 1980s. The periods of most consistent low salinities are 1991 through 1993 and 1972 through 1975. However, the 1992 mean is likely biased downward since the relatively saline station SHIP was sampled only once. Similarly, the 1993 mean is biased downward since station SHIP is not sampled at all.

Utilizing the additional stations which were sampled beginning in 1984, mean salinities for those and the other stations were calculated for the period 1984 through 1993. The resulting mean salinities are delineated on an area map to provide a better sense of the regional salinity patterns (Figure 4). As mentioned previously, an even greater number of stations were sampled during the early 1990's. The data were examined to identify the sampling dates having no missing data for the largest possible number of stations. That period consists of 16 sampling dates within 1991. Of the 42 stations, there is no missing data except stations BM, 53, and 60 each have one missing value. The mean salinities over that period are plotted on a map to show regional salinity patterns and gradients (Figure 5). Because of excessive precipitation that year, salinities were lower than normal. The mean values depicted in Figure 4 are more representative of typical salinities.

Periods of heavy precipitation usually result in reduced salinities throughout the refuge and adjacent marshes. The relationship between salinity and precipitation was investigated by plotting annual precipitation values measured at the Sabine Refuge headquarters (1966-1993) versus the corresponding means of average annual salinities for the interior Calcasieu Estuary stations BC, BN, BS, and BUC (Figure 6). Those stations were chosen to avoid the effects of reservoir discharges down the Sabine River and its tributaries, and to avoid the excessive salinity fluctuations which sometimes occur on the Calcasieu Ship Channel. That graph and the associated linear regression results show that a general relationship appears to exist.

The effects of Sabine River discharge (measured near Ruliff, Texas) on area salinities were investigated by plotting 1990 average monthly river discharges against 1990 average monthly salinities from stations thought to be within the Sabine Estuary. Results of a linear regression using only station SLK (Sabine Lake near the mouth of Willow Bayou) salinities demonstrated the existence of a strong relationship between discharge and salinity (Figure 7). Regression results using a mean from stations SLK, WL, TM, BUC, and C2 revealed the existence of a moderately strong relationship (R squared of 0.63).

As noted above, salinity peaks in the Sabine Estuary are lower than those in the Calcasieu Estuary. Those differences, Regression Output:

Constant		71.534
Std Err of Y Est		6.760418
R Squared		0.533384
No. of Observations		27
Degrees of Freedom		25
X Coefficient(s)	-3.73107	
Std Err of Coef.	0.697948	

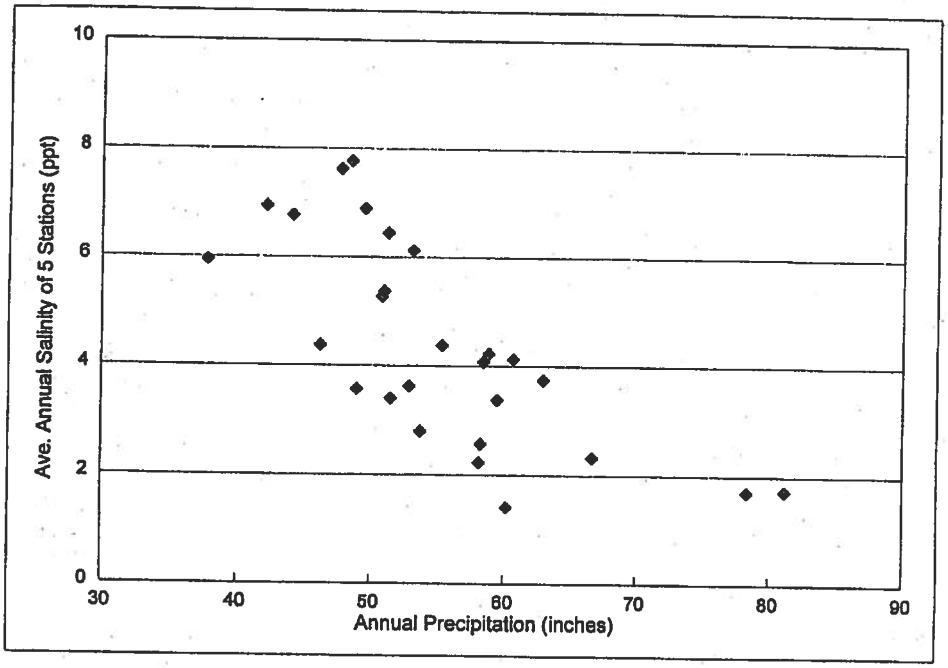
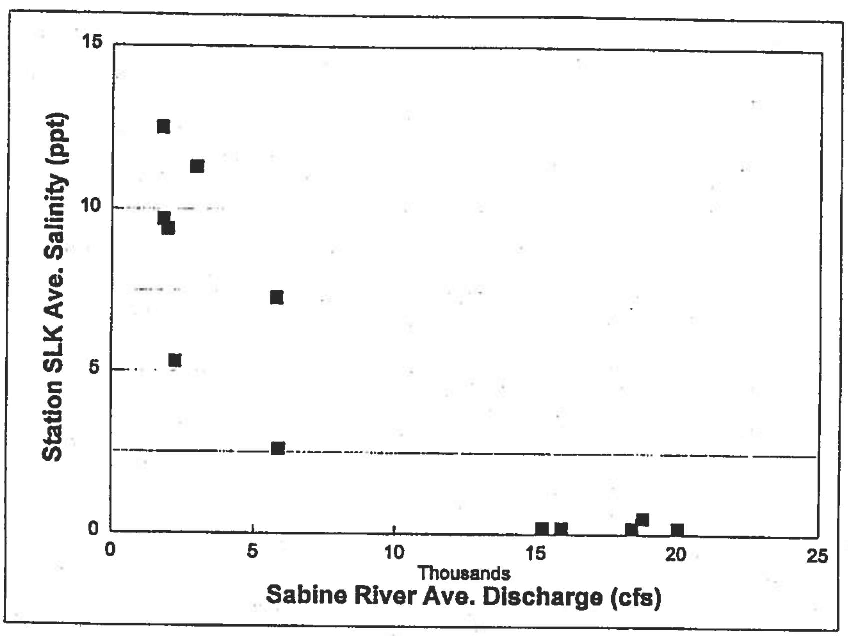


Figure 6. Graph of 1966-1993 annual precipitation versus mean salinities of five interior Calcasieu Estuary stations.



Regression Output:

Constant		10.1294
Std Err of Y Est		2.371581
R Squared		0.784431
No. of Observations		12
Degrees of Freedom		10
X Coefficient(s)	-0.00056	
Std Err of Coef.	0.000093	

Figure 7. Graph of 1990 average monthly Sabine River discharge versus average monthly salinities at station SLK.

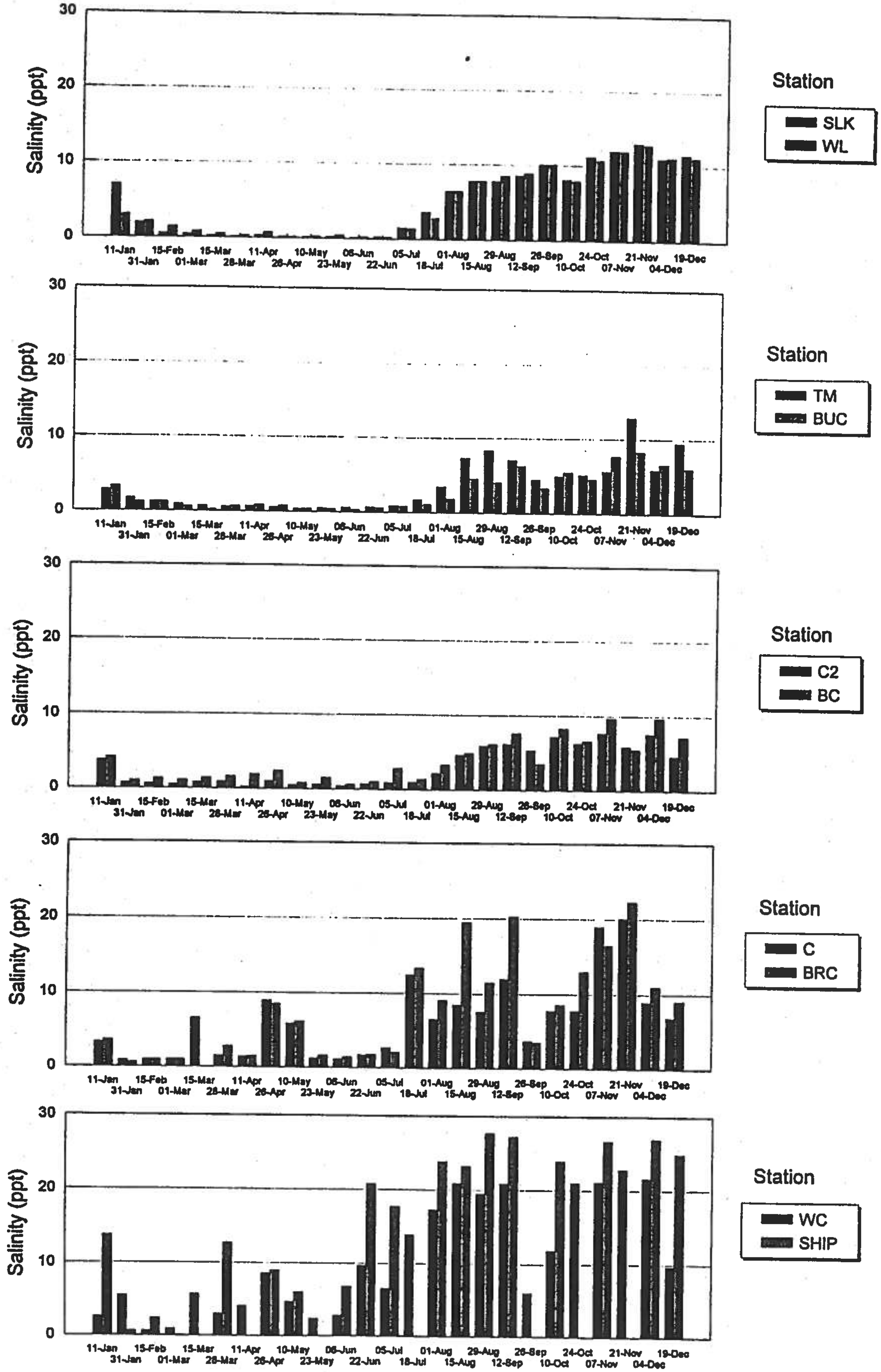


Figure 8. Graphs of 1990 salinities along a transect from Sabine Lake to the Calcasieu Ship Channel.

as well as salinity flux differences, are evident when salinity data along an east-west transect are plotted (Figure 8). As previous data has shown, salinities are lowest in the marshes located approximately midway between Sabine and Calcasieu Lakes. Salinity concentrations and fluctuations are also greater in the Calcasieu Estuary than the Sabine Estuary.

Because the lowest salinities generally occur within interior project-area marshes, precipitation would seem to be the most significant source of freshwater for project-area marshes. Discharge of excess water from Sabine Refuge's Impoundment 3 may also serve as an important freshwater source for adjacent tidally-influenced marshes. Because salinities in the Sabine Estuary tend to be lower than those of the Calcasieu Estuary, it appears that riverine inflow to the Sabine Estuary is also an important source of freshwater. Calcasieu Lake, the GIWW, and the Calcasieu Ship Channel may occasionally serve as freshwater sources, especially following periods of excessive precipitation and riverine input. During such events, salinities in the Calcasieu Ship Channel may rapidly decrease as excess fresh water flows to the Gulf. Following such conditions, the Ship Channel salinities may be lower than that of interior marshes. However, during periods of normal to below-normal precipitation and river discharge, Sabine Lake, Calcasieu Lake, and the GIWW serve as saltwater sources.

FRESHWATER INFLOW MODLING FOR DETERMING NEEDS OF TEXAS BAYS AND ESTUARIES

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The Texas Water Development Board (TWDB) and the Texas Parks & Wildlife Department (TPWD) have jointly established and maintained a data collection and analytical study program, under legislative mandate, which is focused on determining the effect of and need for freshwater inflows to the state's bays and estuaries. Freshwater inflows to the estuaries are compiled from gauged streamflow records and TXRR rainfall-runoff modeling of ungauged drainage areas, with corrections for permitted diversion and return flows from water users. Biological data are compiled from commercial harvest records and coastal fisheries monitoring samples. For the purpose of determining inflow needs, statistical regression models and other numerical analyses are developed to provide quantitative relationships among freshwater inflows, estuarine salinities, and coastal fisheries species. A STELLA compartment model is used to account for nutrient loading, biogeochemical cycling, and develop and the estuarine nutrient budgets. Constraints on the estuary sedimentation, if any, are analyzed using the SED5 accretion model. Results from these models are placed into the TxEMP model, along with information on salinity viability limited for survival, growth, and reproduction of estuarine plants and animals, and solved mathematically to meet state management objectives for maintenance of biological productivity and overall ecological health. TxEMP is a non-linear, stochastic, multi-objective, mathematical programming (optimization) model that was specifically developed as a tool for decision-making on the freshwater inflow needs of Texas bays and estuaries. Solution curves from the TxEMP model are verified by TWDB's TxBLEND modeling of resulting circulation and salinity patterns, as well as TPWD's analyses of species abundance and distribution patterns, in the estuaries. Finally TPWD and the Texas natural Resource Conservation Commission (TNRCC) must jointly evaluate the finding so that TNRCC can appropriately assess the effects of the issuance of water permits within 200 river-miles of the coast. In regard to this statue requirement, the TNRCC, TPWD and the TWDB may establish estuary advisory councils to develop recommendations on alternative management methods for meeting the freshwater inflow needs and maintaining a sound environment in the bays and estuaries.

WATER MANAGEMENT IN TOLEDO BEND RESERVOIR

Barton Rumsey
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Toledo Bend Project, a water conservation project constructed, owned, and operated jointly by the Sabine River Authority of Texas (SRATX) and the Sabine River Authority, State of Louisiana (SRALA) was, contrary to a large majority of the public's opinion, constructed as a multiple purpose project providing for a dependable water supply, hydroelectric power generation, improved navigation on the lower river, and development of a recreation and fishing area. The reservoir was not built for flood control however some benefits will be realized as a result of the operation of the reservoir.

Optimum operating conditions throughout the year are to have a full reservoir in May or June, generate peaking power throughout the prime power period of May through September and then utilize the normal winter and spring rains to generate secondary or off peak power while refilling the reservoir by the next May, all without spilling of water through the spillway.

In accordance with terms and conditions of a long term power sales agreement which expires in 2018, (40 year bond period from 1964 to 2004 and a 14 year additional period) sufficient water is to be provided for the generation of 65,700,000 kilowatt hours of power during the prime power period of each year. In order to produce this power, approximately 1,058,000 acre feet of water will be released over the five month period; 113,000 in May, 115,000 in June, 270,000 in July, 290,000 in August, and 270,000 in September. One acre foot of water is approximately 325,848 gallons and/or that amount which will cover one acre or 43,560 square feet one foot deep. Water releases for power generation range from an optimum of approximately 6,000 cfs for the operation of one unit or approximately 13,000 cfs for the operation of two units to approximately 20,000 cfs for two units at low head differentials. Low head differentials occur at times when spillway releases result in high tailwater elevations. One cubic foot per second is approximately 448.8 gallons per minute.

During the October through April period, the generation of off peak power is directed whenever the reservoir increases above a desired target elevation for the specific months. These target elevations increase gradually over the seven months and are designed to provide for release of some water for generation of power while storing some water each month in quantities proportional to historical inflows. One copy of the current "Operating Guide Rule Curve — Hydroelectric Power Plant, Toledo Bend Dam" is included as attachment A.

Spillway gates are operated only when the reservoir is above a desired target elevation and inflows exceed the releases that can be made through the powerhouse. Basically, releases are initiated whenever the reservoir level exceeds the top of the power pool by 0.5 ft and is rising. The rate at which water is released is dependent upon the elevation of the reservoir; small releases are made when the reservoir is just above the initial elevation but as inflows increase and reservoir elevations increase, the rate of release through the spillway is increased. In this fashion, the maximum instantaneous release from the reservoir is less than the maximum instantaneous flow that would have been experienced should the reservoir not exist due to the storage of some water as reflected by the rising reservoir elevations. This stored water is released over a period of time which has the effect of decreasing the peak flow of the flood while increasing the duration of the flood but at a lesser peak.

In accordance with terms and conditions of the amended and revised Federal Energy Regulatory Commission license for the Toledo Bend Project, a continuous release of 144 cfs from the reservoir is made through two 20" pipes at the spillway. This release is made to satisfy streamflow requirements in the section of the river below the dam and between the spillway exit channel and the powerhouse exit channel.

Releases from the reservoir are sometimes required to supplement the natural flow in the river downstream in order to maintain the minimum average daily flow at Ruliff projected necessary to meet water needs for industrial and agricultural uses as specified in the original Feasibility Study. These releases are minor if totaled yearly and unless they continue over an extended period, are minor as monthly totals.

Historically, total annual releases for power generation range from a low of 937,160 AcFt in 1981 to a high of 6,392,470 AcFt in 1991 with a 1969-1995 average of 3,630,640 AcFt. The total annual spillway releases range from a low of 45,600 AcFt in 1977 to a high of 4,202,080 AcFt in 1969 (1,805,230 AcFt under normal conditions in 1989) with a 1969-1995 average of 649,060 AcFt. The total annual inflow ranges from a low of 1,126,300 AcFt in 1971 to a high of 7,732,880 AcFt in 1991 with an average of 4,207,130 AcFt. The 1969-1995 total inflow is 114,576,270 AcFt while the total releases are 116,651,240 AcFt (98,027,370 AcFt or 84% regulated releases through the powerhouse and 18,623,870 AcFt or 16% unregulated releases through the spillway gates).

During the water year 1994-1995, total diversions from the reservoir were reported to be 4,277 AcFt for municipal use (1,173 by Texas and 3,104 by Louisiana) and 17,718 AcFt for industrial use (all by Louisiana) while total diversions from the river below the reservoir were reported to be 10,101 AcFt for irrigation (2,025 by Texas and 8,076 by Louisiana), 96,338 AcFt for industrial use (52,930 by Texas and 43,408 by Louisiana), 429 AcFt for municipal use (139 by Texas and 290 by Louisiana), and 93 AcFt for recreational use (all by Louisiana).

OPERATING GUIDE RULE CURVE HYDROELECTRIC POWER PLANT, TOLEDO BEND DAM

MONTH	RESERVOIR STAGE FT. MSL	PLANT OPERATION
October through	Below 168	No power generated.
December	Above 168	Operate plant up to full capacity.*
January	Below 168.5	No power generated.
	Above 168.5	Operate plant up to full capacity.*
February	Below 169.0	No power generated.
	Above 169.0	Operate plant up to full capacity.*
March	Below 169.5	No power generated.
	Above 169.5	Operate plant up to full capacity.*
April	Below 170	No power generated.
	Above 170	Operate plant up to full capacity.*
May	Any stage	Use 113 M Ac. Ft. Prime Power.*
	Above 172	Operate plant up to full capacity.*
June	Any stage	Use 115 M Ac. Ft. Prime Power.*
	Above 172.3	Operate plant up to full capacity.*
July	Any stage	Use 270 M Ac. Ft. Prime Power.*
	Above 172.5	Operate plant up to full capacity.*
August	Any stage	Use 290 M Ac. Ft. Prime Power.*
	Above 172	Operate plant up to full capacity.*
September 1-30	Any stage	Use 270 M Ac. Ft. Prime Power.*
	SECONDARY POWER AS FOLLOWS:	
Sept. 1-15	Above 171	Operate plant up to full capacity.*
Sept. 16-30	Above 170	Operate plant up to full capacity.*

NOTES:

1. Maximum turbine discharge, capacity 30 M Ac. Ft. per day.
2. Release 100 cfs from storage when power plant is shut down.
3. Releases will be in quantities sufficient to provide a minimum average monthly flow at Ruliff of 1500 cfs during 7 month period October-April, and 3000 cfs during 5 month period May through September.
4. When pool stage is at or above 172.5 and inflow is greater than power plant capacity, operate spillway in accordance with "Guide on Spillway Gate Operation."
5. Authorities will notify companies as to flow conditions in the Sabine River as required by Section 5.07 of the Power Sales Agreement.
6. Control stages set forth above are to be maintained only to the extent possible when making releases through the power plant. Spillway gates are to be opened only when stages specified in the "Guide on Spillway Gate Operation" are reached.
7. During prime power season when stage of lake is near upper limit maintain close watch on inflow and make releases for secondary power generation to avoid spillway releases if possible.

* Releases to be determined based on best judgment considering upstream conditions, stages at Ruliff, and inflows below dam. Generating schedule to be approved by the Authorities prior to plant operation.

Year	Low Elev.	High Elev.	Inflow M AC FT	RWRHSE Releases	Power MWH	SPWY Releases	Total Releases	Elev. 12/31
1968	149.93	173.38	983.81	0.00	0	1099.25	10999.25	172.06
1969	166.94	173.41	5268.70	1718.67	99545	4202.08	5920.75	168.27
1970	168.28	171.78	2362.14	1766.43	121236	258.70	2025.13	170.18
1971	168.57	170.45	1126.30	1056.00	71779	72.66	1128.66	170.17
1972	166.21	171.92	2473.60	2319.86	159990	62.50	2382.36	170.71
1973	168.94	173.06	7522.30	6301.30	412844	936.81	7238.11	172.51
1974	167.91	173.40	6183.80	5141.16	341178	1061.04	6202.20	172.41
1975	167.57	172.97	5302.40	5404.36	360948	539.57	5943.93	168.74
1976	166.86	172.60	2668.38	2673.52	187260	65.81	2739.33	168.31
1977	165.90	172.23	2541.85	2720.06	188573	45.60	2765.66	166.92
1978	166.84	171.03	1686.62	1232.70	83841	60.37	1293.07	169.33
1979	168.70	172.78	6514.78	5744.98	386304	785.24	6530.22	169.24
1980	166.88	172.87	3472.90	3185.37	209575	656.58	3841.95	166.98
1981	166.79	172.08	1590.09	937.16	63013	255.18	1192.34	169.41
1982	168.01	172.37	3183.31	1698.13	108857	1033.43	2731.56	171.99
1983	167.75	173.22	4369.32	4084.12	268947	750.67	4834.79	169.45
1984	167.47	171.89	2709.83	2623.84	173083	130.21	2754.05	168.88
1985	167.16	172.19	3422.73	2790.88	194026	129.50	2920.38	171.88
1986	166.91	173.03	4061.88	3975.30	273390	296.87	4272.17	170.84
1987	164.77	172.40	3587.34	3758.77	249409	129.03	3887.80	168.65
1988	165.92	170.95	2502.82	2578.56	174593	131.15	2709.71	167.76
1989	166.86	173.93	6610.95	4831.37	319703	1805.23	6636.60	167.60
1990	166.63	173.18	6141.78	5127.82	343947	767.99	5895.81	169.10
1991	164.95	173.48	7732.88	6392.47	424227	1531.91	7924.38	167.76
1992	167.42	173.06	5711.03	4721.14	316624	669.47	5390.61	169.72
1993	164.78	172.85	5083.08	5410.39	357000	359.79	5770.18	165.64
1994	165.39	172.12	4596.83	4644.66	296488	123.41	4768.07	170.00
1995	165.00	173.10	5164.82	5188.35	364626	663.82	5852.17	165.91
1996								
TOTALS			114576.27	98027.37	6551006	18623.87	116651.24	
1969-1995 Average	166.87	172.53	4207.13	3630.64	242629.85	649.06	4279.70	169.20

PLANT COMMUNITIES OF COASTAL WETLANDS SURROUNDING SABINE LAKE; FACTORS CONTROLLING PLANT ZONATION

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Wetlands are often exhibit zonation of plant communities. These zones are ares which are dominated by a few characteristic plant species and are thought to be the result of the interaction of abiotic and biotic factors. While hydrology is usually cited as the most important factor influencing wetland zonation (i.e. the zones occur along a gradient of inundation period), salinity, soil type, herbivory and fire frequency are factors which also have been cited as influencing plant communities in Sabine Lake wetlands. The relative importance of these factors has not been well studies. Their interaction with an unpredictable climate add to the complexity of assigning factors importance levels regarding the causation of Sabine Lake wetland zones. Wetland zones surrounding Sabine Lake are shown. Factors responsible for the observed zonation are illustrated. Examples of contradiction to conventional wisdom and examples which highlight the dominance of uncertainties are given.

Historical Development of the Marsh System on the West Side of Sabine Lake

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Restoring hydrology, which in effect should restore function and productivity in coastal marshes, is a priority mission of the Upper Coast Wetland Ecosystem Project within the Texas Parks and Wildlife Department. Interior coastal wetlands and marshes associated with Sabine Lake are of special concern to TPWD. For wetland hydrology to be restored, a thorough understanding of historical changes within the natural drainage systems must exist. Taylor's Bayou, and the Neches and Sabine Rivers are the 3 major drainages associated with Sabine Lake in Jefferson and Orange Counties. Taylor's Bayou and it's tributaries drain the vast majority of Jefferson County. The Neches and Sabine Rivers drain vast areas of east Texas and west Louisiana, and both empty into Sabine Lake.

Development within the marshes West of Sabine Lake began as early as 1860 with the construction of a 25 mile long railroad from Beaumont to Sabine Pass (Pitts 1861). Development continues today with the widening of highways and navigation channels, surface development of waterfront property, drainage activities, and oil, gas, and mineral extraction.

Coastal wetlands are being lost at an accelerating rate in Texas. From 1956 to 1978, approximately 936 ac/yr of coastal wetlands were converted to open water, compared to the period from 1930 to 1956 when 138 ac/yr were lost (Morton and Paine 1990). The most extensive losses of interior coastal wetlands in Texas — 12,632 ac, which is more than one-half of the total wetland loss — have occurred along the Neches River Delta (White et al. 1987, Morton and Paine 1990). In total, over 90% of the emergent marshes in the Lower Neches River Delta have been converted to open water (White et al. 1987, Morton and Paine 1990).

Factors likely contributing to wetland loss in the Neches River Delta include (1) subsidence associated with active faulting or induced by extraction of oil, or gas, (2) sea level rise, which is exacerbated by dredge spoil deposition, levee and road construction, and storm protection systems, and (3) altered hydrology, sediment deposition, and salt budget due to dredging and leveeing channels and canals for the purpose of navigation or mineral extraction (Johnson and Gosselink 1982, Morton and Paine 1990, White and Tremblay 1995). Wetland loss due to salt water intrusion, an indirect impact of dredging coastal wetlands, is significant, and is far more important than the direct loss associated with canal construction (U.S. Dept. of the Interior 1994). Canals and navigation channels allow tidal salt water to encroach into low salinity wetlands, which leads to the subsequent conversion of those wetlands to open water. Wetland conversion to open water accounts for as much as 75% of the wetland loss in some states (U.S. Dept of the Interior 1994). Open water is formed when salt intolerant vegetation dies and the underlying organic top soil material erodes away before the succession of salt tolerant vegetation can take place (Dozier 1983).

All of the tributaries of Taylor's Bayou have been affected by development. These tributaries include Salt Bayou, Big Hill Bayou, Mayhaw Bayou, Hillebrandt Bayou, Alligator Bayou, and the North and South Forks of Taylor's. Mud Bayou entered into Sabine Lake as a drainage between the 2 cheniers associated with Sabine Pass, and supported a total drainage area of approximately 9 square miles (Gillham 1898). Aerial photos indicate that Mud Bayou was filled with dredge material as Port Arthur Canal modifications progressed.

Construction of the Eastern Texas Railroad in 1861 on a levee along the west side of Sabine Lake was the first development impacting flood waters within the Taylor's Bayou drainage. According to testimony at a General Land Office hearing in Port Arthur in 1962, early residents reported that shortly after the rail line was completed a major rainfall event caused severe flooding along the Salt Bayou drainage. Complaints were aired that the railroad embankment was curtailing sheet flooding from the marsh into Sabine Lake, so the railroad company dug a ditch under the railroad into Sabine Lake. This ditch marked the first major human alteration of the historic drainage (TPWD 1990).

In 1898, the Army Corps of Engineers granted the Kansas City, Pittsburg, and Gulf Railroad and the Port Arthur Channel and Dock Company permission to connect the Port Arthur Canal to the Sabine Channel. The construction plan called for the closure of Mud Bayou between the canal and the lake. The plan also called for the opening between Keith Lake and Sabine Lake to be closed. Gillham (1898) stated: "There is now an opening from this lake into Sabine Lake which has scoured out to considerable depth. It is, however, an artificial channel, and has only existed a comparatively short time, it having been cut through as a ditch, it is said, to allow rowboats to get into the lake. It is our purpose to close this channel between the canal and Keith Lake and also between the canal and Sabine Lake. The conditions which originally existed here, as maintained by nature, will be reproduced and in no way be affected by the canal construction."

The Sabine-Neches Canal between Port Arthur and the mouths of the Neches and Sabine Rivers was completed to dimensions of 9' by 100' in 1908. Between 1914 and 1916, the Sabine-Neches Canal was deepened to 25' and extended to Beaumont (Wilson 1981).

The Gulf Intracoastal Canal segment that passed through Southeast Texas was completed in 1933 and utilized a portion of the existing Port Arthur Ship Channel. The Gulf Intracoastal Canal crossed and obliterated several miles of Salt Bayou immediately north of Shell Lake, and also severed that portion of Salt Bayou immediately north of Star Lake. Shortly thereafter, the lower portion of Taylor's Bayou was re-routed to join the Gulf Intracoastal Canal (Stutzenbaker 1990).

The Intracoastal Canal Project included the construction of large concrete water control structures on both sides of the canal at Star Lake, at the outfall of Salt Bayou and the Intracoastal Canal, and at the Little Keith Lake Cut on the Port Arthur Canal. These control structures were built to allow private landowners to control water levels in the marsh and to exclude unwanted tidal salt water from the marshes (TPWD 1990).

When time and the erosion from tidal energy and ship traffic began to damage the water control structures, the local sponsors chose not to fund needed repairs and the landowners could not handle the sizeable repair costs. Thus, the structures fell into a poor state of repair and eventually became inoperable (TPWD 1990).

In 1966, the Army Corps of Engineers leveed Little Keith Lake and filled the entire lake with dredge spoil from the adjacent ship channel (TPWD 1990). This action once again eliminated tidal water access to Keith Lake from the Port Arthur Canal.

The following excerpt is taken from *The Texas Gulf Historical and Biographical Record*, Volume 17(1), November 1981. It was in an article titled "History of the Salt Water Barrier on the Neches River," by Paul C. Wilson:

> "In July 1777, while Generals George Washington and Sir William Howe were maneuvering their forces in New Jersey, the British hydrographer George Gauld and his party were on a more peaceful mission off the coast ofTexas and Louisiana. John Payne, in the surveying sloop *Florida*, sounded Sabine Pass and Sabine Lake and noted on his crude map that he found "fresh water" at the upper end of Sabine Lake. So we might also today, had man not altered the natural environmental conditions.
>
> Prior to 1900 there was no salinity problem in the Neches River. Water demands were moderate, and a natural bar at the mouth of the river helped prevent salt water from the Gulf of Mexico from intruding on the river in concentrations sufficient to contaminate the fresh water intakes. With the introduction of rice cultivation in Jefferson County in the 1890's and the construction of the deep draft channel to Port Arthur by the Port Arthur Canal and Dock Company in 1897-98, this picture began to change. These changed conditions, coupled with the drought of 1901, brought about a salt-water problem on Taylor's Bayou and the Neches River...
>
> ...On October 18, 1902, Assistant Engineer A. H. Weber of the New Orleans District, Corps of Engineers, reported as follows about a salinity problem:
>
> 'Salt water has been noticed on several occasions above Beaumont and for from one to four days of each year at Smith's Bluff, 10 miles above the mouth. During the period of salt water, pumping at the irrigation plants must be discontinued, as the effect of the salt on the rice crop is very injurous. No serious results, however, have been experienced from this source on the Neches, owing to the short duration of the salt-water period, but on Taylor's and Hillebrandt's bayous the loss to the rice producers from salt water has been heavy.'
>
> Mr. Weber further stated that rice planters along Taylor's and Hillebrandt's Bayous desired a salt water guard lock, either in the Port Arthur Canal, or on Taylor's Bayou, to prevent salt water from entering Taylor's Bayou.
>
> The Sabine-Neches Canal between Port Arthur and the mouths of the Neches and Sabine Rivers was completed to dimensions of 9 feet by 100 feet in 1908. This canal did not cause any appreciable encroachment of sea water into the Neches River. The turning point was reached, however, when the Sabine-Neches Canal was deepened to 25 feet, and the 25 foot channel to Beaumont was constructed in 1914-1916...
>
> ...In his unfavorable report dated March 5, 1910, considering the construction of 25 foot channels to Beaumont and Orange, Captain A. E. Waldron, Dallas District Engineer, stated that...
>
> 'the rice growers did not want deep water unless some means was provided to prevent the salt water from reaching the Neches and Sabine Rivers. They insisted that a lock or guard gates be installed in the Port Arthur Ship Canal or in Taylor's Bayou, and in the Sabine Neches Canal, which would be kept closed during low water periods, and thus keep salt water from reaching these streams.'
>
> A salt water barrier dam, diversion canal, and navigation lock were constructed on Taylor's Bayou by the Beaumont Navigation District of Jefferson County, Texas, in 1914. a replacement dam, located 400 feet

upstream from the old dam, was constructed by the same agency in 1935...

...The guard lock in the Sabine-Neches Canal, downstream from the mouth of the Neches River was authorized in 1911...

...Deepening the channel to Beaumont from 25 feet to 30 feet was authorized in 1922. The project document contains the report of John M. G. Watt, Assistant Engineer in charge, Dallas District, dated January 7, 1919, questioning the value of the salt water guard lock.

A detailed salinity survey of the Sabine Lake area was conducted by Captain Arthur P. von Deesten, Corps of Engineers, between February 1921 and December 1923...

...Captain von Deesten's study showed that the authorized 30 foot project, which would increase canal cross section by 55 percent and increase the canal depth by 20 percent, would increase average salinities at all river (surface water intake) stations about 20 percent and surface salinities about 10 percent.... The removal of the guard lock as an obstruction to navigation was authorized by the River and Harbor Act of March 3, 1925.A by-pass channel was constructed around the lock, and the lock was later removed during fiscal years 1952-53...

...Subsequent to the extension of the deep draft channel to Beaumont in 1914-16, salt water intrusion became a major problem on the Neches River at Beaumont...

... Since 1925 the navigation channel from the Gulf of Mexico to Beaumont has been repeatedly deepened in increments of two and four feet and widened in several increments to its present dimensions of 40 feet deep and 400 feet wide. These dimensions were authorized in 1962 and the enlargement of the Neches River Channel was completed in 1972...

...In the early years of the development of the Sabine Neches Waterway, salinity intrusion was regarded as a consequential damage of the navigation improvements, and its prevention as a total local responsibility."

Public ownership of marshes on the West side of Sabine Lake began with the purchase of 8,200 acres of marsh North of the Gulf Intracoastal Canal in 1958 from the McFaddin Ranch by the Texas Parks and Wildlife Department. This purchase was made with waterfowl stamp funds and funds derived from the sale of hunting licenses, and firearms and ammunition. The property was acquired as a representative tract of coastal wetlands to be developed and maintained for migratory waterfowl use, wildlife management research and demonstration, and public hunting and fishing recreation. During the years 1959 through 1964, some 56 miles of levees were constructed around 6,880 acres of existing natural marsh to develop eleven wetland management compartments associated with Big Hill Bayou and to prevent dewatering of the marsh by the then proposed Taylor's Bayou Drainage Project (Sutherlin 1995). The Lost Lake Unit, south of the Gulf Intracoastal Canal, was acquired in 1983 through mitigation for portions of the Taylor's bayou Drainage Project. This tract along with the purchase of the 126 acre Round Lake in 1988 with waterfowl stamp funds totals approximately 4,200 acres. Today this property is administered by the Texas Parks and Wildlife Department's Wildlife Division as the J.D. Murphree Wildlife Management Area.

The Parks Division of the Texas Parks and Wildlife Department purchased the 15,109 acre Sea Rim State Park from Planet Oil and Mineral Company in 1972. This tract had earlier been a part of the McFaddin Ranch. Immediately after the park was purchased, the marsh was opened for hunting and fishing. Shortly thereafter, interest developed in opening a cut through the former Little Keith Lake into the ship channel for improved water circulation into the Salt Bayou Drainage system. Biological recommendations called for using a dragline to open a shallow meandering cut from the ship channel into Keith Lake. Hydraulic pressures would then be expected to open the cut to the depth and width necessary to handle water movement (TPWD 1990).

A wide assortment of private, business, political, and governmental interests became involved in the decision to open a "water exchange pass". The end result was a hydraulically dredged 3,600 foot straight line canal, 155' wide and 5 and _' deep with 2:1 side slopes. The project was completed and approved for payment in September 1977 after the Mineral Company granted an easement to the Parks and Wildlife Department for construction of the channel across their land. The project was funded by the U.S. Department of Agriculture's Soil Conservation Service through the Southeast Texas Rural Conservation and Development Project (TPWD 1990).

In 1980, the US Fish and Wildlife Service purchased the 42,956 acre McFaddin National Wildlife Refuge directly west of the existing Sea Rim State Park. The NWR purchase was made using federal waterfowl stamp funds (TPWD 1990).

In 1987, as partial mitigation for wetland impacts associated with the Taylor's Bayou Drainage Project, funding was acquired to replace the deteriorated water control structure on the south side of the intracoastal canal at Star Lake. The new water control structure was relocated to the north end of Perkin's Levee on Star Lake. This new structure restored water management to Star Lake and marshes west of Perkin's levee on the McFaddin NWR.

In 1990, a joint water management plan was developed for Sea Rim State Park, McFaddin NWR, and the J.D. Murphree WMA. This Plan called for replacement of water control structures at Salt Bayou (constructed by the Army Corps of Engineers in 1995) with joint funding provided through the Corp of Engineer's 1135b program, Texas Parks and Wildlife Department, and Ducks Unlimited. Later phases of the Salt Bayou Project will address the need to reduce tidal energy and continued erosion of the Keith Lake Water Exchange Pass while allowing for ingress and egress of marine organisms.

The Salt Bayou Plan also addresses the need to consider the continued impacts of mud-boat ditches constructed in the 1950's and 1960's. These ditches were developed by hunting clubs to access to their leases.

During the 1940's, several long cattle access levees were constructed with participation of private landowners and the USDA. These cattle walks exist today and several are still in use. They have had varying degrees of impact on wetland hydrology. The walks are located on portions of the McFaddin, White, Sabine Pass, and LaBelle Ranches. The Perkins Levee on McFaddin NWR is a major drainage separation for the Star Lake pasture. The Willow Slough levee now serves as the main reservoir embankment for the Willow Slough Marsh on McFaddin NWR and Sabine Ranch.

Four major oil fields have been developed in marshes west of Sabine Lake since the mid 1920's. These fields are still producing oil and gas in limited quantities today. They are the Bessie Heights Oil Field in Orange County, the Clam Lake Oil Field on McFaddin NWR, the Shell Lake Oil Field on Sea Rim State Park, and the Gum Island Oil Field on LaBelle Ranch. New interest in redevelopment of existing oil fields is apparent from the intensive geophysical seismic work ongoing in marshes west of Sabine Lake. Oil field access has been developed in marshes using levee berms, board roads, and canals constructed to drill wells from barge delivered oil rigs. Surface development for oil and gas extraction have adversely impacted the hydrology of these marshes.

Development of State Highways 87 and 73 has altered hydrology in Orange and Jefferson County marshes.

Efforts by Louisiana Department of Natural Resources through the Coastal Wetlands Protection and Restoration Act to restore coastal marshes of the Chenier Plain in Louisiana have clearly demonstrated the effectiveness of wetland restoration technology. The Texas and Louisiana Chenier Plains share many of the same problems associated with wetland degradation. In many cases these problems are more advanced on the Texas side of Sabine Lake due to the longer history of development.

The emphasis on interbasin transfer of water from the Sabine Basin as a solution to Texas water problems needs careful deliberation. Long term impacts from restricted freshwater inflows to the entire Sabine Lake ecosystem should be weighed against impacts to coastal marsh plant communities and wildlife values, as well as marine fisheries. These impacts should be considered before making further changes to the system. We should also implement plans in individual drainages which will artificially restore hydrology to the best of our abilities. The same tools can be used to restore wetlands that were used to develop navigation, drainage, and minerals. We have reached a final environmental crossroads and it is time to develop a plan for Neches and Sabine River waters. This plan should restore marsh production and provide for commercial, industrial, municipal, residential, agricultural, and environmental needs.

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SABINE RIVER WATER QUALITY

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The Sabine River Authority of Texas (SRA) has had a basinwide water quality monitoring program since 1972. This program has primarily concentrated on monitoring the main-stem of the Sabine River, SRA's three water supply reservoirs and several principal tributaries included in the classified segments in the Texas Surface Water Quality Standards.

The Texas Clean Rivers Program (TCRP) enacted in 1991, has strengthened SRA's watershed monitoring program. This program allows SRA to monitor unclassified tributaries (subwatersheds) and along with the routine program to develop a Sabine River Watershed Management Program (SRWMP).

The SRWMP utilized an approach that includes a geographic information system (GIS) to inventory water quality concerns on a subwatershed basis, to collect and analyze water quality data that meets quality assurance criteria, to use biological monitoring to screen subwatershed areas, to perform targeted monitoring to benefit point source discharges, and to encourage public input through a basinwide steering committee and public meetings.

The recently completed Draft 1996 Water Quality Assessment for the Sabine River Basin show that the lower Sabine River flowing into Sabine Lake exhibits good water quality. Local tidal bayous such as Cow Bayou and Adams Bayou are impacted from anthropogenic pollution which is made worse by the sluggish flow and tidal effects on these bayous.

WATER QUALITY IN CALCASIEU LAKE

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The Calcasieu River Basin is located in southwestern Louisiana. Originating in headwater in the hills west of Alexandria, Louisiana, the Calcasieu River flow generally south for about 160 miles to the Gulf of Mexico. The River mouth is at Cameron, Louisiana, approximately 30 miles east of Sabine Pass and the Texas-Louisiana state line. This paper reviews past studies of water quality in the Calcasieu River/Lake/Estuary system. Water quality in the Lake and estuarine complex are assessed using monitoring data provided by the Louisiana Department of Environmental Quality (LDEQ) Additionally, water quality within other Louisiana coastal water bodies is compared to that observed in the Calcasieu system.

There are dramatic difference in land use between the Lower Calcasieu Lake/Estuary system (the lower 40 mild below the Saltwater Barrier) and the upper riverine system. Overall land use in the Calcasieu Basin (LDEQ, 1990) is 50.8 percent forest, 26.$ percent agriculture, 11.8 percent wetland, 2.6 percent urban, and 5.7 percent water. LDEQ divides the basin into subsegments. For example, LDEQ subsegment 04, located in the Lower Calcasieu Basin, includes Calcasieu Lake. Land use in subsegment 04 is 46.3 percent water, and 43.2 percent wetland. Thus, land use in the most southern region of the basin is markedly different from that in the upper basin.

A number of water quality studies have been performed within the lower Calcasieu Basin. These studies are not exhaustively cited or reviewed here, however, a selected number are included to provide an indication of their diversity, and to suggest the need for additional studies. Lafleur (1956) report chemical data from 1951 and 1955. Denoux (1976) analyzed plankton communities and incorporated selected water quality analyses in his study of the Lower Calcasieu from Jun 1974 to December 1975. The U.S. Army Corps of Engineers, New Orleans District (USACOE, 1977) conducted water quality studies in 1975076 in the Lower Calcasieu which investigating of maintenance dredging impacts, and include regular monitoring data taken from a site near the Saltwater Barrier. DeLaune, et al. (1984) studied nutrient levels and eutrophic state of the Lower Calcasieu. Sampling for this study was performed from March through December 1984. The Louisiana District of the U.S. Geological Survey has also performed a number of studies on circulation, environmental toxicology, and water quality of the Calcasieu River.

The Louisiana Department of Environmental Quality performed six intensive water quality surveys on the Lower Calcasieu in July 1978, October 1978, July 1979, August 1979, July 1980, and June 1984 (Duke, 1985). These studies provided water quality and hydrological data for the entire Lower Calcasieu over short time periods. A major purpose of these studies was to provide support for water quality modeling to determine appropriate water discharge permit limitations.

An extensive study of both biological and chemical water quality was conducted by McNeese State University from October 1983 through August 1986. Sampling stations were located from the Saltwater Barrier to the mouth of the system at Cameron, Louisiana. Tributaries to the Lower Calcasieu were also sampled.

HYDROLOGY

Area and discharge

Owing to the interchange of flow between basins, boundaries of drainage areas in the lower Calcasieu Basin are uncertain. Sloss (1971) estimates the drainage area of the Calcasieu River Basin at the Gulf of Mexico to be 3,772 square miles. This compares with 20,944 square miles for the Sabine River Basin at the Gulf. Drainage areas of the lower portions of the Sabine and Calcasieu Basins are based on judgment because of the connection formed by the Intracoastal Waterway. Drainage area of the Calcasieu River above the City of Lake Charles at the Saltwater Barrier is estimated to be 3,100 square miles (Duke, 1985). Forbes (1988) classifies the "Lower Calcasieu River" as that part of the system extending from about 10 miles north of the city of Lake Charles (near the saltwater barrier) to the Gulf of Mexico. In addition to the Ship Channel from the city of Lake Charles to the Gulf of Mexico, and the Intracoastal Waterway, the dominant features of the Lower Calcasieu include a series of shallow lakes. Physical data for these lakes are presented in Table 1. For comparison, Sabine Lake and Toledo Bend Reservoir are also listed in this table.

Freshwater discharge enters the Lower Calcasieu primarily from the Calcasieu River. The U.S.G.S> discharge monitoring station at Kinder on the Calcasieu River (station No. 08015500, 1700 square miles drainage area) is most commonly used to characterize freshwater contribution to the Lower Calcasieu. Based on a drainage area ratio, the freshwater discharge entering the Lower Calcasieu from the Calcasieu River at Lake Charles would be 82 percent larger than the discharge monitored at Kinder. Annual and monthly average discharge at the kinder station are graphed in Figure 3. Maximum and minimum discharges over the period of record are 182,000 and 136 cfs respectively. Statistics including the 7Q10 flow (minimum annual 7-day average flow recurring once in 10 years), the 10, 30, 50, 70, and 90 percentile flows, minimum and maximum daily flows over the period of record are listed in Table 2 (Forbes, 1988). For comparison, statistics of the Sabine River near Ruliff, Texas (station No. 08030500, 9329 square miles drainage area, water year 1967-1995, USGS, 1995), area also presented in this table. Retention time of the Lower Calcasieu is roughly 33 days at mean discharge, and 420 days at 7Q10.

The Lower Calcasieu is subject to tides from the Gulf (Forbes, 1988) The diurnal tide range at the mouth is approximately 2 feet, and are slightly attenuated at the Saltwater Barrier. Above the Saltwater Barrier, tides stages are small but detectable. Wind, rather than tide, causes, the extreme stage events in the Lower Calcasieu, with stages at the City of Lake Charles falling several feet below sea level during sustained winds out of the north.

Table 1. Dominant Lakes of the Lower Calcasieu River (Shampine, 1970).

Name	Suface Area (Sq. Miles)	Volume (Acre-Ft)	Avg. Dept (Ft)
Mud Lake	3.85	3,700	1.5
Black Lake	3.4	8,770	4.0
Calcasieu Lake	67	210,000	4.9
Moss Lake	1.0	—	—
Prien Lake	1.53	5,320	5.4
Lake Charles	1.74	9,650	8.7
Sabine Lake*	87	301,000	5.4
Toledo Bend Reservoir*	284	4,450,000	24.5

**Not in Calcasieu Basin, listed for comparison.*

Table 2: Discharge statistics (cfs).

Discharge Statistic	Calcasieu River at Kinder	Calcasieu River at Kiner (estimated)	Sabine River near Ruliff
Mean Annual	2600	4732	8378
7Q10	203	369	432
10 percentile	6120	11,138	18,900
30 percentile	2270	4131	—
50 percentile	1030	1875	5240
70 percentile	538	979	—
90 percentile	319	581	1230
Minimum	136	248	278
Maximum	182,000	331,240	108,000

Table 3: Selected LDEQ coastal monitoring sites

Basin	Site #	Description	Symbol
4	58010109	Chef Menteur Pass at Chef Menteur	LPCM
4	58010035	Pass Rigolets	LPPR
4	58010138	Lake Pontchartrain (Causeway Crossover #4)	LPCW
2	58010295	B. Lafourche near Golden Meadow	BLGM
2	58010008	Little Lake at Temple	LLT
12	58010348	Bayou Grand Caillou south of Houma	BGC
12	58010351	Caillou Lake south of Houma	CL
6	58010316	Vermilion Bay South of New Iberia	VB
5	58010310	White Lake Southwest of Abbeville	WL
5	58010029	Mermentau River near Grand Cheniere	MRGC
3	58010093	Calcasieu River at Moss Bluff	CRMB
3	58010027	Calcasieu River near Lake Charles	CRLC
3	58010026	Calcasieu River near Burton Landing	CRBL
11	58010091	Sabine River Northeast of Orange	SROR

Table 4: Median parameter values for 1992-93 at selected coastal monitoring sites

Symbol	Temp (Deg. C)	pH	DO (mg/L)	Cond (umhos/cm)	CL (mg/L)	Turb (NTU)	Secchi (In.)	TDS (mg/L)
LPCM	20.8	7.2	8.0	8775	2649.5	10	24	5039
LPPR	21.6	7.2	9.0	6900	2180.0	11	22	3537
LPCW	20.0	7.1	8.9	5980	1787.5	4	41	3282
BLGM	21.3	7.5	6.6	6880	2293.0	12	—	3852
LLT	22.0	7.5	8.2	1203	326.0	17	18	723
BGC	23.5	7.1	6.2	1930	521.5	20	—	1081
CL	21.6	7.8	7.9	12805	4133.0	18	15	7534
VB	21.0	7.6	8.1	4910	1445.5	26	7	2157
WL	21.5	7.0	8.6	436	98.4	155	—	471
MRGC	21.1	7.5	7.8	23850	7856.5	39	6	14720
CRMB	21.2	6.7	6.5	66	8.6	27	10	112
CRLC	22.1	7.1	5.8	2525	656.0	19	15	1347
CRBL	21.7	7.2	6.0	12045	3825.0	15	18	6880
SROR	20.7	7.0	5.9	149	17.4	11	17	128

Table 5: Median nutrient concentrations for 1992-93 at selected coastal monitoring sites

Symbol	TOC (mg/L)	TP (mg/L)	NOx (mg/L)	TKN (mg/L)	TN (mg/L)	TN:TP
LPCM	7.2	0.06	0.03	0.55	0.58	9.67
LPPR	7.3	0.07	0.03	0.59	0.62	8.86
LPCW	5.7	0.04	0.02	0.40	0.42	10.50
BLGM	9.1	0.10	0.13	0.85	0.98	9.80
LLT	9.4	0.10	0.36	0.81	1.17	11.70
BGC	9.1	0.17	0.22	0.99	1.21	7.12
CL	8.4	0.09	0.03	0.71	0.74	8.22
VB	8.9	0.15	0.20	0.72	0.92	6.13
WL	10.3	0.20	0.30	1.08	1.38	6.90
MRGC	7.3	0.17	0.13	0.73	0.86	5.06
CRMB	8.3	0.11	0.07	0.65	0.72	6.55
CRLC	10.6	0.11	0.10	0.96	1.06	9.64
CRBL	8.9	0.11	0.13	0.99	1.12	10.18
SROR	8.7	0.06	0.05	0.81	0.86	14.33

History of hydrological modification

The hydrology of the Lower Calcasieu has been modified to improve navigational access (Forbes, 1988). In the late 1800's the channel through Calcasieu Lake had a maximum depth of 13 feet, and a 30foot depth existed across a bar at the northern end of Calcasieu Pass between Calcasieu Lake and the Gulf of Mexico. In 1871, the U.S. Army Corps of Engineers made its first report on navigation in the Calcasieu which resulted in construction of a 5-foot deep by 80-foot wide navigation channel through the bar. By the late 1930's this 50foot deep channel had been deepened to 13 feet.

A 30-foot deep by 125-foot wide deep-draft channel along the route of the present Intracoastal Waterway between the Sabine and Calcasieu Rivers was completed between 1937 and 1940. The present-day Gulf Intracoastal Waterway (GIWW) crosses the Calcasieu River Ship Channel just north of Calcasieu Lake. The GIWW is maintained at a depth of 12 feet and a width of 25 feet. A lock 2.5 miles east of the Ship Channel was completed in 1952, and reduces saltwater movement east toward Grant Lake.

Begun in 1941, the Calcasieu Ship Channel replaced the Lake Charles Deep Water Channel. The Ship Channel originally provided 30-foot deep by 250-foot wide access from the Gulf to the City of Lake Charles. In 1968, the channel was extended to a depth of 40 feet and a width of 400 feet. The route of the channel follows the western edge of Lake Charles. A 40 foot deep mooring basin south of Lake Charles I 350 feet wide and 2000 feet long. The thalweg elevation of the Ship Channel is generally near or below -40 feet. This depth results in dense highly saline water filling the channel trench. An upstream flow within this saltwater wedge is frequently observed replacing saltwater lost to erosion of the sedge into the overlying fresher flow.

A saltwater barrier just north of the City of Lake Charles was completed in 1968. The structure includes a navigation lock and a flood control barrier. The flood control barrier consists of 5 adjustable gates. The barrier is operated to maintain a stage of 2.5 feet on the upstream side of the structure. The purpose of the structure is to minimize movement of saltwater and particularly

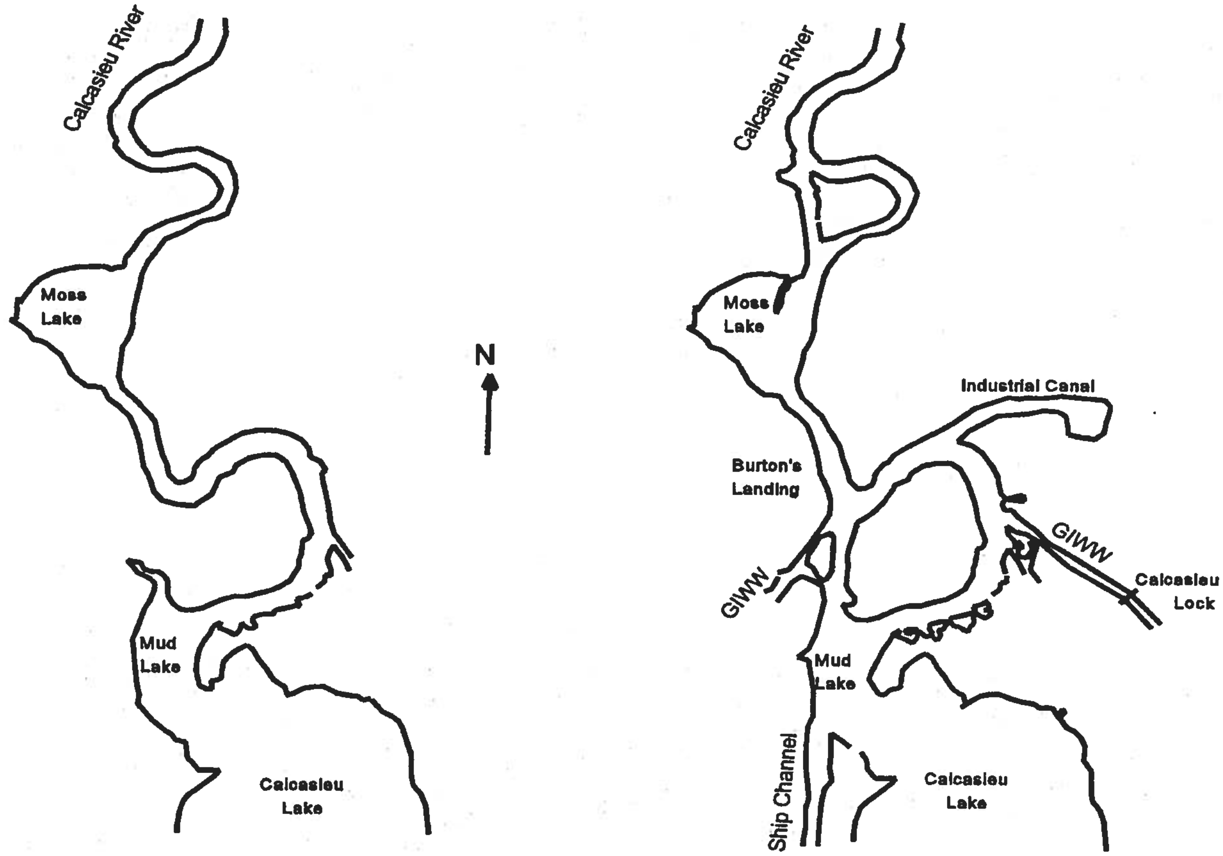

Figure 1. Lower River showing natural river pattern (left), and modified River (right), as adapted from Thompson (1986).

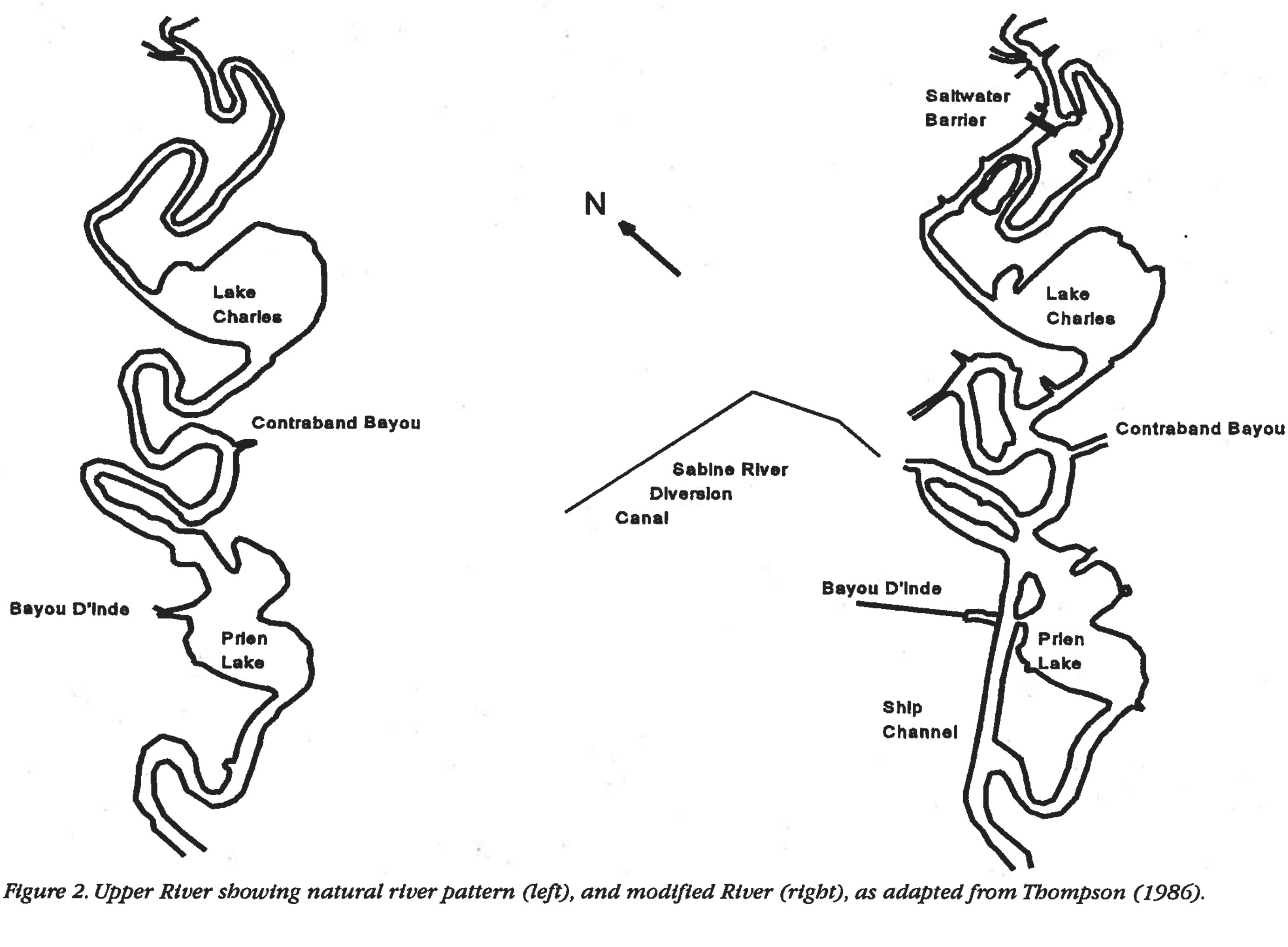

Figure 2. Upper River showing natural river pattern (left), and modified River (right), as adapted from Thompson (1986).

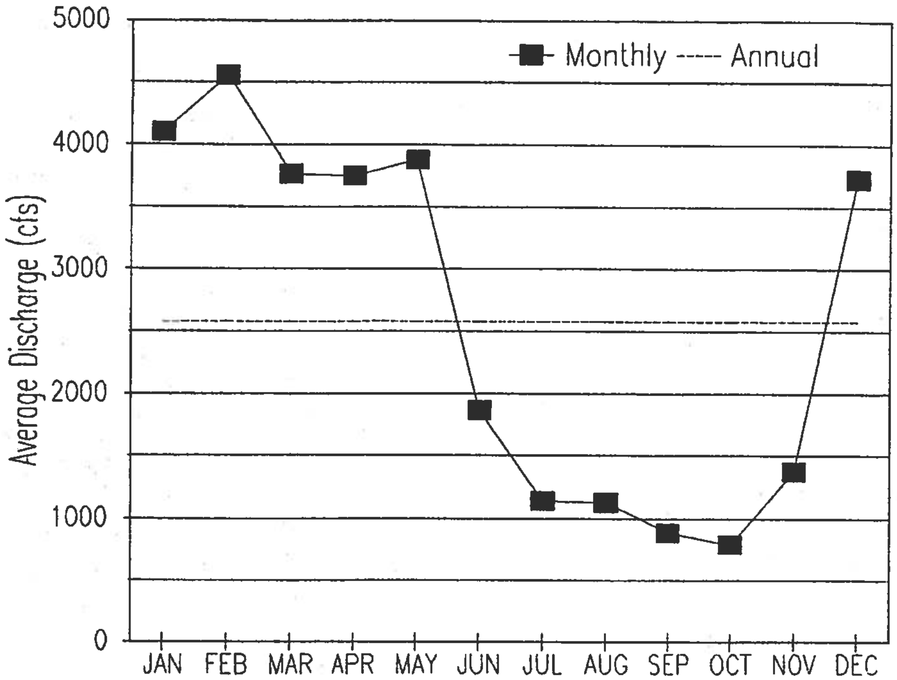

Figure 3.Average monthly and annual discharge in the Calcasieu River at Kinder, La.

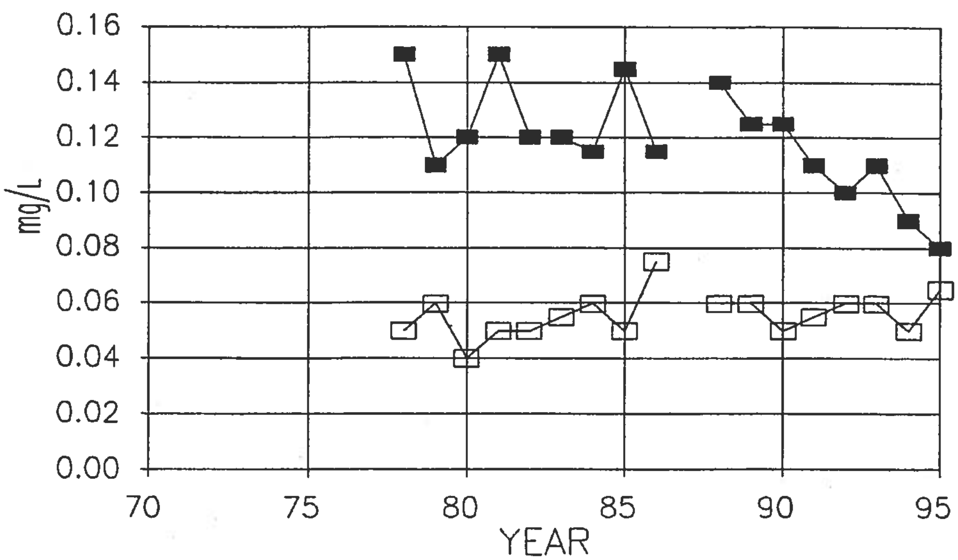

Figure 4.Annual median total phosphorus (mg/L) in the Calcasieu (solid marker) and Sabine (open marker).

a saltwater wedge into the deep upstream channels.

In addition to other hydrological impacts, channel dredging has also resulted in spoil bank levees isolating channels from adjoining lakes and wetland (DeRouen and Stevenson, 1987). Although breaches have been cut in these levees, the levees still cause a directed circulation tending to channel freshwater through the Ship Channel to the Gulf without mixing. The levees also reduce enrichment of wetlands by sediments and freshwater, and potentially reduce ingress and egress of estuarine species.

WATER QUALITY

Water quality standards

The Calcasieu Basin is designated as basin number three, and is classified into twelve segments which are further classified into subsegments (LDEQ, 1996). Most of the basin has designated uses of primary and secondary contact recreation and propagation of fish and wildlife. Dissolved oxygen criteria for most of the Calcasieu River above the saltwater barrier is 5.0 mg/L. However, the upper Calcasieu River from the confluence with marsh Bayou to the Saltwater Barrier is designated as naturally dystrophic waters, and have seasonal DO criteria of 3.5 mg/l from May through October. Under the Louisiana Natural and Scenic River System, some of the upstream reaches of the Calcasieu River and tributaries above the Saltwater Barrier are classified as scenic. For segments downstream of the Saltwater Barrier, DO criteria are designated 4 or 5 mg/L.

Toxic water quality assessment

LDEQ (1992) assesses the estimated size of waterbodies affected by toxic pollutants. It is estimated that 10.9 miles of the Calcasieu River (from buoy 112 to buoy 106, including Coon Island Loop), 1114 acres of Lake Charles, and 1083.5 acres of Prien Lake are affected by organic halogenated aliphatic and aromatic priority pollutants. Subsegments of the Calcasieu River, Calcasieu Lake, and Prien Lake are under informational fishing advisories by the Louisiana Department of Health and Hospitals (LDHH) and the LDEQ, notifying the public that priority organic contamination has been found. This joint advisory advises against fishing and consumption of seafood from the area, and against swimming, wading, and water sports in Bayou D'Inde. The source of this pollution is listed as industrial point source.

Section 304(l) of the Clean Water Act requires states to prepare lists of waterbodies which are not expected to achieve applicable water quality standards for toxic pollutants after technology based requirements have been met. Several segments of the Calcasieu Basin have been listed (LDEQ, 1992). Listed segments include Bayou Verdine (030306), Bayou D'Inde (030901), Calcasieu River and Ship Channel (030301), and Prien Lake (030303). Causes for listing include halogenated aliphatic and aromatic priority pollutant organic chemicals, and, in Bayou Verdine, phenol and nickel. Point source dischargers listed under section 304(l) include PPG, Conoco, and Vista.

Salinity

Salinity below the Saltwater Barrier is dependent on the intensity of freshwater inflow. Surface salinity is typically lowest near the Saltwater Barrier, and increase as the Gulf is approached (Duke, 1985). Typically, a "saltwater wedge: is observed in the Ship Channel. The existence of this wedge affects circulation patterns, water quality, and biological indicators of water quality.

Nutrients and eutrophication

Chlorophyll-a concentration is a common measure of algal biomass. Long-term monitoring of chlorophyll-a concentrations have not been maintained within this basin. Denoux (1976) reported average chlorophyll-a concentrations in the Lower Calcasieu to be 13.7 and 15.7 ug/L in oligohaline (less than 10 ppt) and medium salinity (greater than 10 ppt) samples, respectively. Denoux found highest chlorophyll-a values in the summer of 1974 for oligohaline sites, and the fall of 1974 for the medium salinity sites, however, values observed in the summer and fall of 1975 were lower and did not follow the seasonal pattern observed in 1974. DeLaune, et al. (1984) report the site average values of chlorophyll-a in the Lower Calcasieu ranged from 17-21 ug/L during their sampling in 1984. Chlorophyll-a level peaked in July 1984, with a mean of 44 ug/L, and four of 12 stations exceeding 50 ug/L.

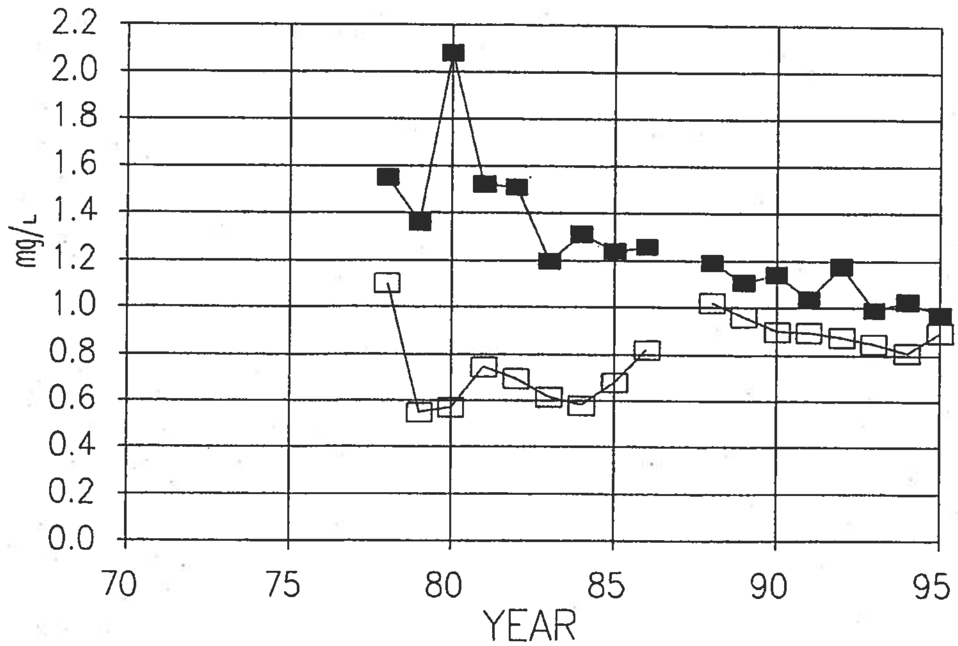

Figure 5. Annual median total nitrogen (Mg/L) in the Calcasieu (solid marker) and Sabine (open marker).

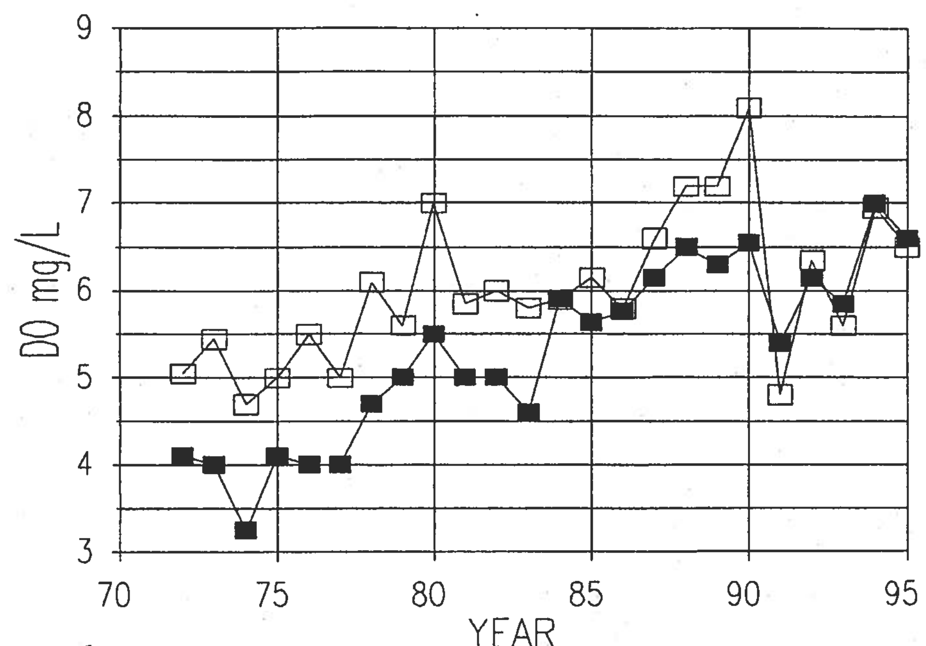

Figure 6. Annual median dissolved oxygen (mg/L) in the Calcasieu (solid marker) and Sabine (open marker).

Although DeLaune, et al. state that determination of eutrophic state is complex, they conclude that based on phosphorus, nitrogen and chlorophyll-a levels the Lower Calcasieu can be classified as somewhat eutrophic.

Maples (1987) reported a mean value of 26 ug/L for samples in Lake Calcasieu. In this study chlorophyll-a values were highest in winter, high in summer, and lowest in the fall. Maples found chlorophyll-a values were negatively correlated with temperature (r=-0.45), and positively correlated with conductivity (r=0.34). Maples also discusses an observed bloom of a red tide organism, *Gonyaulax monilata*.

The LDEQ measured chlorophyll-a concentrations during three of their six intensive water quality surveys of the Lower Calcasieu (Duke, 1985). Chlorophyll-a was found to range from 3 to 40 ug/L in July 1979, 10 to 30 in July 1980, and 2 to 14 in June 1984. Lowest values were observed at the saltwater barrier. In 1979 and 1980 maxima were observed midway between the Saltwater Barrier and the Gulf; in 1980, the maximum concentration was observed nearest the gulf.

In summary, chlorophyll-a concentrations in the Lower Calcasieu are highly variable. Concentrations have often been observed at levels which would be considered elevated. Regular long-term monitoring of chlorophyll-a concentration by a singe agency would assist in the assessment of trophic status as well as contribute to an improved understanding of factors controlling algal abundance.

The LDEQ performs monthly monitoring of water quality parameters including nutrient levels at Burton's Landing (Figure 1). Over the past decade, annual median total phosphorus (Figure 4) and total nitrogen (Figure 5) are apparently declining at this station. For comparison, median values for the Sabine River at Orange, Texas are also plotted in Figures 4 and 5.

Dissolved oxygen

Depth average concentrations of dissolved oxygen in the Lower Calcasieu are generally below saturation and display a minimum near the saltwater barrier (Duke, 1985). A second minimum, or DO sag occurs below the City of Lake Charles, and is associated with pollutant loading from point source dischargers. LDEQ monitoring data for surface (1 meter depth) DO concentration at Burton's Landing indicate that annual median concentrations have been rising over the period-of-record (Figure 6) from approximately 4 mg/L in the mid 70's to approximately 6 mg/L in the 90's. Again, median annual values from the Sabine River at Orange are plotted for comparison. Annual first and third quartile concentration values show patterns similar to the trend of the annual median concentration. This rising trend in DO may result from improved wastewater treatment from point sources in the Lower Calcasieu. Wetland water quality is often associated with organic enrichment and low DO. Rising DO in the Lower Calcasieu may, in part, also be related to reduction of water exchange with coastal wetlands due to wetland impoundment and coastal wetland loss.

Comparison of Louisiana Coastal waterbodies

Selected LDEQ coastal monitoring sites are listed in Table 2. Basins in Table 2 are listed from east to west; the LDEQ basin numbers listed here correspond to Pontchartrain (4), Barataria (2), Terrebonne (12), Vermilion (6), Mermentau (5), Calcasieu (3), and Sabine (11). Published median water quality parameters for these sites over 1992-93 are listed in Tables 3 and 4. Table 3 lists water temperature (Temp), pH (pH), dissolved oxygen concentration (DO), temperature compensated conductivity (Cond), chloride concentration (Cl) turbidity (Turb), secchi disk depth (Secchi), and total dissolved solids (TDS). Table 4 lists total organic carbon (TOC), total phosphorus (TP), nitrite plus nitrate nitrogen (NOx), total Kjeldahl nitrogen (TKN), total nitrogen (TN), and the mass ratio of TN to TP (TN:TP). Total nitrogen is the sum of NOx and TKN. In comparison to other coastal sites, the Lower Calcasieu sites, (CRLC and CRBL) exhibit low dissolved oxygen and intermediate nutrient levels.

Pollution source

The Lower Calcasieu Basin receives discharges from numerous municipal and industrial point sources (Duke, 1985). Most of the dischargers are located in the area between the Saltwater Barrier and the Intracoastal Waterway. Municipal dischargers include the City of Lake Charles, the City of Sulphur, and the Town of Westlake. Industrial dischargers include Olin Corp., PPG Industries, CITGO, W.R. Grace, Certain-Teed, Himont, and Firestone. A few dischargers are located south of the Intracoastal Waterway, particularly in the area of Cameron.

Produced water, or oil field brine, a byproduct of the oil production process (LDEQ, 1992), is also discharge into the Lower Calcasieu. St. Pe (1990) reports that approximately 68 million gallons per day are discharged into the Louisiana waters from 510 discharge points. Oil field brines are often highly saline, usually more than two to three times more saline than seawater. Because of high salinity, these discharges are dense, and flow along the bottom or into sediments without significant mixing. Produced waters may be high in radioactive radium 226, and hydrocarbons. Although coastal produced water discharges are being phased out, historic discharge sites are a focus for environmental concern.

Hydrological and water quality modeling

Duke (1985) reviewed water quality modeling and associated hydrological modeling in the Lower Calcasieu. Duke applied the RECEIV-II model in the calculation of a total maximum daily load (TMDL) for conventional oxygen-demanding pollutants. The TMDL assumes a 7Q10 freshwater discharge. Waldon (1988) updated this model to reflect changes in discharger locations and design flows. NUS Corporation, under contract to PPG, performed modeling studies of toxic pollutants in the Lower Calcasieu using the EPA WASP model (NUS Corp., 1990; reviewed by Waldon, 1990).

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Addendum

MODELS AND DECISION MAKING FOR THE LAY PERSON

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A model of a natural system can be defined as any simplified quantitative representation of that system. In estuary management, use is made of both statistical models and deterministic models, both of which are usually implemented on a digital computer. The objective of applying either of these models is to be able to effect predictions of features of the estuary under specifies external conditions. Such predictions then provide a basis for the evaluation of past of proposed actions that could affect the estuary. The circumstances that dictate a choice between a statistical or deterministic model are outlined. Both types require data from the real system, but the use of that data in the modeling process is different. The principal steps of model development are enumerated, and the advantages and disadvantages of each types of model are summarized. The specific problem of the modeling of a water-quality parameter in Sabine Lake is given as an example. A philippic is delivered on models in estuary management and the fallacies that commonly occur.

HUMAN USES IN THE SABINE-CALCASIEU BASINS

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EARLY HUMAN USES

The original inhabitants of the Sabine-Calcasieu Basin were American Indians from the Attakapas tribe. These native Americans were rumored to be cannibalistic, however, this assertion has never been clearly proven. In spite of a harsh environment filled with mosquitoes and often threatened by fierce tropical storms and hurricanes, the Attakapas found abundant food resources due to the diversity and richness of fish and wildlife resources found throughout the region.

The waters and marshes were teeming with finfish, blue crabs, oysters, clams, furbearers, white-tailed deer, alligators, and various species of fowl. The wooded cheniers were also rich with wildlife including the black bear, a species now absent from the region. Large concentrations of Indian artifacts have been unearthed by settlers or exposed due to increased coastal erosion along the many east-west cheniers located throughout the region. Stone arrowheads have also been found indicating that trade outside the coastal region to the north must have been prevalent.

Many historians feel certain that Jean and Pierre LaFitte frequented the region making temporary camps along the wooded cheniers during their many excursions "trading" along what is now the Texas and Louisiana Gulf coast. Throughout history, settlers were told of hidden treasures left by LaFitte along the coastal bayous and cheniers in the region. Modern treasure hunters continue to look even today for the rumored riches.

The region remained largely uninhabited after the United States was established. The boundary between the U.S. and Mexico (now Texas), drawn at the Sabine River, was not officially settled until 1819. Prior to the boundary settlement, the disputed region (the Sabine-Calcasieu Basins) developed into a virtual "no-man's land" devoid of official supervision from both countries. The area became a favorite hideout for criminals which contributed to it's slow settlement.

The large tracts of virgin live oak forests located on the old abandoned beach ridges (cheniers), were declared naval forest reserves by Congress in the early 1800s. With most navy ships in the early 1800s constructed of hardwood, these vast oak forests were thought to be needed for shipbuilding. When metal became more readily available, the forested cheniers were released and granted to settlers from throughout the U.S. east coast.

The first settlers were from the Southeast U.S. and were of Anglo-Saxon lineage. Later arrivals were from French Louisiana or decedents of the Acadians from Nova Scotia, Canada. The higher, wooded cheniers were settled first, followed by the coastal prairies to the north.

Post-Civil War Human Uses

After the Civil War, commerce in the region began to flourish with the establishment of a more organized agricultural and natural resource-based economy. Livestock produced both on the cheniers and in the firmer marshes included beef cattle, goats, hogs, and horses. Even today wild hogs, cattle and horses can sometimes be seen in isolated marshes in the region. Crops produced by the settlers on the high ridge lands located on the cheniers included cotton, sugarcane and oranges. Trapping of fur animals was also extremely important to the region, supplying much needed winter income to many residents. Important fur animals found in the region included muskrat, mink, raccoon, opossum, and otter. Muskrats were the most plentiful and valuable fur animal at the time. This designation remained until the introduction of the nutria in the 1930s by E. A. McIlhenny on Avery Island, Louisiana. After the introduction of nutria (a native of Argentina), their numbers increased tremendously until they largely replaced the niche occupied by muskrat. Nutria first began being harvested in the region during the 1950s and surpassed the muskrat in catch and value in the 1960s. Today the nutria is the most important fur animal in the region both in numbers harvested and in value to the trapper.

With no roads into the region, the Sabine-Calcasieu region utilized the numerous waterways in the area for trade. Schooners made regular runs to and from Galveston, Texas and New Orleans, Louisiana loaded with goods produced on the cheniers (especially oranges). The traders returned from these larger ports with many goods that could not be produced in the region.

The environment was extremely harsh for early settlers. Mosquito populations were often so extreme that livestock would die from stress. Additionally, killer tropical storms and hurricanes periodically hit the region and caused widespread loss of both property and lives. One of the worst hurricanes to hit the region was Hurricane Audrey in 1957 which made landfall near the Sabine River mouth, killing over 500 people in Cameron Parish alone.

During the early 1900s the region continued to be a major producer of both fur and alligator skins. Additionally, market hunting for ducks, geese and waterbird plumage became very important to the commerce of the region. With the establishment of formalized game laws in the 1930s, however, the waterfowl focus shifted to sport hunting. Numerous hunting camps were established and visitors from throughout the U.S. came into the area to enjoy world class duck and goose hunting each winter. One very popular waterfowl hunter who visited the region was President Franklin Roosevelt.

Numerous state and federal wildlife refuges were established in the region during the early 1900s in an attempt by conservationists and philanthropists to preserve winter waterfowl habitat. Many of these refuges still exist and are being expanded today as public support for fish and wildlife habitat protection continues to grow in the U.S. Additionally, compatible human uses such as nature-based tourism, sport hunting, and commercial alligator hunting are allowed today on many federal refuges under strict U.S. Fish and Wildlife Service oversight.

Post World War II Human Uses

Fur trapping, seafood production and alligator hunting continued to be important to the economy of the region after WWII. Overharvest of alligators, however, began to be problematic into the 1950s and early 1960s. Commercial alligator hunting was halted in the early 1960s to allow for recovery of the population. After extensive research conducted largely by the Louisiana Department of Wildlife and Fisheries, an experimental commercial hunting season was conducted in Cameron, Vermilion and Calcasieu Parishes in the early 1970s. From this successful experiment, an organized, heavily-managed alligator hunting season has now been re-established throughout Louisiana and in southeast Texas.

After WWII, development of commerce in the region continued to largely center around fish and wildlife resources until large deposits of oil and gas were discovered in the 1940s. With the finding of oil and gas, immense wealth was brought into the region. This led to the establishment of modern roads into the area, increased population, and the migration of the workforce from traditional jobs in agriculture, seafood and trapping to higher paying jobs in oil and gas exploration and production and marine transportation. Major ports along the Sabine and Calcasieu Rivers in Port Authur and Lake Charles, respectively, allowed for a dramatic increase in trade worldwide. Both the Calcasieu and Sabine Rivers had to be straightened and deepened to allow for deep draft ocean ship traffic. Manufacturing and refining of petroleum-based products such as gasoline became established in the region north of the cheniers and many workers found better paying jobs and new lives in the port cities to the north. Large deposits of oil and natural gas continued to be discovered in the region into the 1980s and increased prices for petroleum-based products continued to bring almost embarrassing wealth to both state and local governments.

Oil and gas industry growth required the construction of numerous man-made canals used for oil rig transport to exploration sites in the marsh. These canals interconnected with the deep draft ship channels and allowed a drastic increase in saltwater intrusion into marshes that were traditionally fresher. Due to this increased saltwater intrusion into interior marshes, freshwater vegetation began to deteriorate and wildlife and fisheries habitat began to disappear. Areas that had traditionally been densely covered with lush marsh vegetation began to open up into large bodies of open water. Declines in wildlife productivity were experienced. Reduced utilization by waterfowl, furbearers, alligators, and wading birds became clearly evident and many residents began to ask difficult questions. It seemed to sink in that the fish and wildlife resources that had always been so plentiful in the region were not infinite. Innocent habitat alterations in the name of economic development were in fact causing the death of "the goose that laid the golden egg" - the diverse coastal marshes along the southwest Louisiana and southeast Texas Gulf coast.

In the mid-1980s the "oil boom" went bust in Texas and Louisiana and the focus began to shift more toward sustainable renewable natural resources for long-term economic health. Many oil and gas workers moved into the commercial fishermen sector or left the region. Jobs were hard to find, marsh deterioration continued to increase, and increased pressure on seafood resources continued to grow with record numbers of commercial fishermen working the Louisiana-Texas coastal waters and marshes. Innovative shrimping techniques such as butterfly nets, four-rig trawlers, and monofiliment cast-nets spread throughout the region allowing for maximum utilization of shrimp resources that were largely being artificially produced due to increased saltwater intrusion. As the marshes deteriorated, energy entering the food chain as detritus increased leading to a short-term increase in available marine nursery habitat and food. The question of sustained seafood production, however, began to loom in the minds of many coastal ecologists - a question that continues to be the primary focus today!

MODERN HUMAN USES

Modern human uses in the Calcasieu-Sabine basins reflect the historical uses outlined above with significant shifts taking place as a result of both economic, environmental and regulatory-related changes.

Seafood Industry - The seafood industry continues to be economically important in the region. Important fisheries species produced and processed include menhaden, shrimp, blue crabs, oysters, and several species of nearshore finfish. Offshore commercial finfish important to the region include red snapper, vermilion snapper, king mackerel, and Spanish mackerel. Conflict between commercial finfishermen and sport fishermen surrounding the use of gill nets and the designation of game fish status for speckled trout and red drum remains. Increased regulations relating to sea turtle conservation, by-catch reduction, and overfishing continue to further impact seafood harvesters. Water quality problems associated with human populations (fecal coliform) and past industrial discharges continue to threaten future seafood safety. A fish consumption health advisory is still in affect in some parts of the Calcasieu estuary. Additionally, all of the available oyster resources in Sabine Lake and most of the oyster reefs in Calcasieu Lake are off limits to fishermen due to water quality problems. Coastal restoration projects that stop or slow the rate of coastal erosion will be essential to the continuation of a sustainable commercial fishery in the region. Few argue that in coastal Louisiana and Texas, "Wetlands = Fisheries". This includes both quantity and quality of wetlands.

Sport Fishing - The economic impact of sport fishing visitations and enterprises continues to grow in the region. Expenditures by recreational fishermen contribute significantly to the economies of the coastal communities in the area. The number of inshore, nearshore and offshore sport fishing guide businesses continues to grow and attract a growing number of sport fishermen into the region. Additionally, thousands of residents and non-residents enjoy shoreside recreational fishing activities each year for blue-crabs, shrimp, and finfish. Sustainability of this important renewable natural resource-related use will also require increased vigilance toward slowing coastal marsh loss in the region. Without estuarine habitat, fisheries productivity will inevitably decline.

Sport Hunting - Even though continental waterfowl populations experienced declining populations through the 1980s, their numbers have dramatically increased in the 1990s. These conservation gains have allowed for longer duck and goose hunting seasons and more generous limits. Visitation by waterfowl hunters is again on the rise, and the number of hunting clubs and hunting guide businesses are increasing. Expenditures by waterfowl hunters also significantly benefits all coastal communities. Sustainability of this important renewable natural resource-related use will largely hinge on successful coastal restoration and conservation of coastal marshes in the future.

Fur Resources - Since the early 1980s the world market for fur has drastically declined. Pelt prices to the trapper have dropped so low that many have halted trapping operations. This has led to major increases in both muskrat and nutria populations in some areas, resulting in marsh "eat-outs." Eat-outs cause increased marsh deterioration and habitat loss. Only with improved worldwide markets for fur products will the trapping industry survive. Prices predicted for the 1996-97 season are much improved, however, and many trappers in the region expect to start up or increase trapping operations this winter.

Alligator Resources - With the successful recovery of the American Alligator in the region, commercial hunting seasons are now conducted during the Fall of each year. In fact, the harvest of alligators continues to be one of the most economically valuable surface uses of private marshlands in the region. The growth and popularity of alligator meat, traditionally a by-product, has also increased the value of this important renewable resource to the region. Alligator "ranching", (the harvesting of eggs from alligator nests for use in producing hatchlings for alligator farming enterprises) continues to supply much needed private landowner income and help supply the baby alligators needed for the growing number of alligator farms in the region.

Eco-tourism - With the decline in oil and gas related jobs, there has in recent years been a growing recognition of the potential for the region as a tourism Mecca. The diverse fish and wildlife resources and wetland habitat that abounds in the coastal region of southwest Louisiana and southeast Texas is world class, surpassing many popular destinations such as the Florida Everglades. Birders from throughout the world travel to the region to see the many neotropical migrants that utilize the wooded cheniers after a long migration across the Gulf of Mexico. Additionally, many tourists come to the region to experience unique wildlife species such as the alligator, roseate spoonbills, white pelicans, numerous species of shorebirds and wading birds, and the many millions of ducks and geese that overwinter in both the marshes and flooded agricultural fields that abound in the area. Almost one-half million acres of wildlife refuges are located in the region and all are at least seasonally open to the public. Development of nature trails and visitors' centers at these refuges have helped to increase public access to popular eco-tourism related sites. This has led to increased tourism-related expenditures and jobs in the region. Coastal leaders have re-directed their economic development efforts more toward tourism expansion in recent years with expanding anti-litter campaigns and beach cleanups. Most economists believe that tourism will continue to be a growth industry in the region; however, continued efforts must be made to implement long-term coastal restoration projects that assure sustainable marshes into the future.

Agriculture - Significant agricultural products produced in the region today include (1) beef cattle and hay in the marsh and on the cheniers, and (2) rice and improved pasture in the prairies to the north. Cattlemen continue to use coastal marshes in the region as rangeland, often seasonally burning off old growth marsh grass so that new succulent shoots can grow for improved grazing quality. Additionally, several alligator farms have been established in the region through the availability of "ranching" -program alligator hatchlings. With continued healthy markets for both meat and skins, this agricultural enterprise should be a growth industry in the future. Continued cattle and alligator production will be important in the future, however, efforts to halt coastal erosion will be critical to the sustainability of healthy marsh rangelands in the region.

Aquaculture - The most important aquaculture related commodity produced in the Sabine-Calcasieu Basins is crawfish. Crawfish production is often rotated with commercial rice production in the prairies to the north. Limited production, however, also occurs in leveed marsh impoundments that are pumped out to allow for proper water/forage management. Regulatory restrictions pertaining to marsh levee construction have virtually halted impoundment establishment in the region, and aquaculture expansion is not expected to grow in the marsh. Crawfish production acreage in the coastal prairie region, however, is expected to grow if pondside prices remain at profitable levels.

Oil and Gas Exploration and Production - Oil and gas exploration and production continues to be the most important job and income producer in the region. With the recent introduction of new exploration technology (3-D Seismic Technology), the region has seen a significant increase in both seismic and drilling activity. Many oil and gas industry experts predict a new "mini-boom" within this industry over the next 8-10 years; however, trends predict declining oil and gas reserves, fewer jobs, and movement to deeper offshore production into the next century. The fact remains, however, that oil and gas resources are nonrenewable and a shift to alternative energy sources in the U.S. will be inevitable. Continued production of the reserves already discovered will require protection of the infrastructure now placed in the coastal wetlands. Efforts to halt coastal erosion will be very important to continued oil and gas production throughout the region.

SABINE LAKE WATER QUALITY

Alan Plummer, Jr.
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Sabine Lake water quality conditions are being monitored by several Texas entities including Texas Natural Resources Conservation Commission, Texas Water Development Board, Texas Parks and Wildlife, and Lamar University, and several Louisiana entities. The monitor programs have involved field measurements for dissolved oxygen, temperature, and salinity and laboratory tests for several parameters including coliform, nitrogen, phosphorus, and a number of other selected parameters.

Data collected by these programs will be presented and discussed during this presentation. Additionally, the results of screening analysis of data performed as a part of the Clean Water Program will be presented.

The data collected supports the fact the coastal waters have unique characteristics and can vary significantly from one region to another. In addition to the unique physical characteristics of Sabine Lake, the inflow water quality conditions of contributing streams affects Sabine Lake water quality.

Although there has been a considerable amount of data gathered, it is important that current monitoring programs and special studies continue to gather data which is needed to properly define the quality of water in Sabine Lake. Development of the additional data on a comprehensive basis is critical to assure that conclusions and actions relative to Sabine lake water quality are made based on sound technology and science.